Spectral Harmony for Violists
Part 1: Macrophonic Harmony
John Stulz

1. Overview

The aim of the following text is to prepare violists with the conceptual tools needed to approach spectral harmony in performance. The use of the spectral content of individual sounds as a model from which to build a harmonic language has, since its initial development in France during the 1970s, become a significant element of contemporary music. Three of our major solo works of the past 50 years - Ligeti *Sonata - I. Hora Lungă,* Rădulescu *Das Andere*, and Grisey *Prologue* - make use of spectral harmony. Just as we perform solo Bach with knowledge of the underlying tonal harmony, the assiduous violist must have a firm understanding of spectral harmony in order to successfully perform these works. In addition to these three works, we are confronted with spectral harmony in the ensemble and orchestral works of many living composers, from Kaija Saariaho and Magnus Lindberg to Enno Poppe and Georg Friedrich Haas. Learning the fundamentals for spectral harmony and its application in composition has become an essential tool in the tool box of the modern violist.

2. Overtones and Partials

We can define *spectral harmony* as the use of the spectral content of a sound as a model for the pitch material of a piece.

All sounds can be broken down into a series of component pitches called *partials*. These partials are not sounds in themselves, but rather, as their name implies, represent various individual frequencies occurring simultaneously within a sound. Much in the same way that white light which is refracted through a prism reveals itself to consist of the entire spectrum of colors in the rainbow, each sound contains a unique spectrum of partials vibrating together. The unique series of partials and the intensity at which each partial is present in a sound is what gives that sound its unique color signature, or timbre.

By using a spectrogram to analyze the frequency distribution of a healthy bowed open C String, we can see the spectrum of pitches hidden inside of the note.

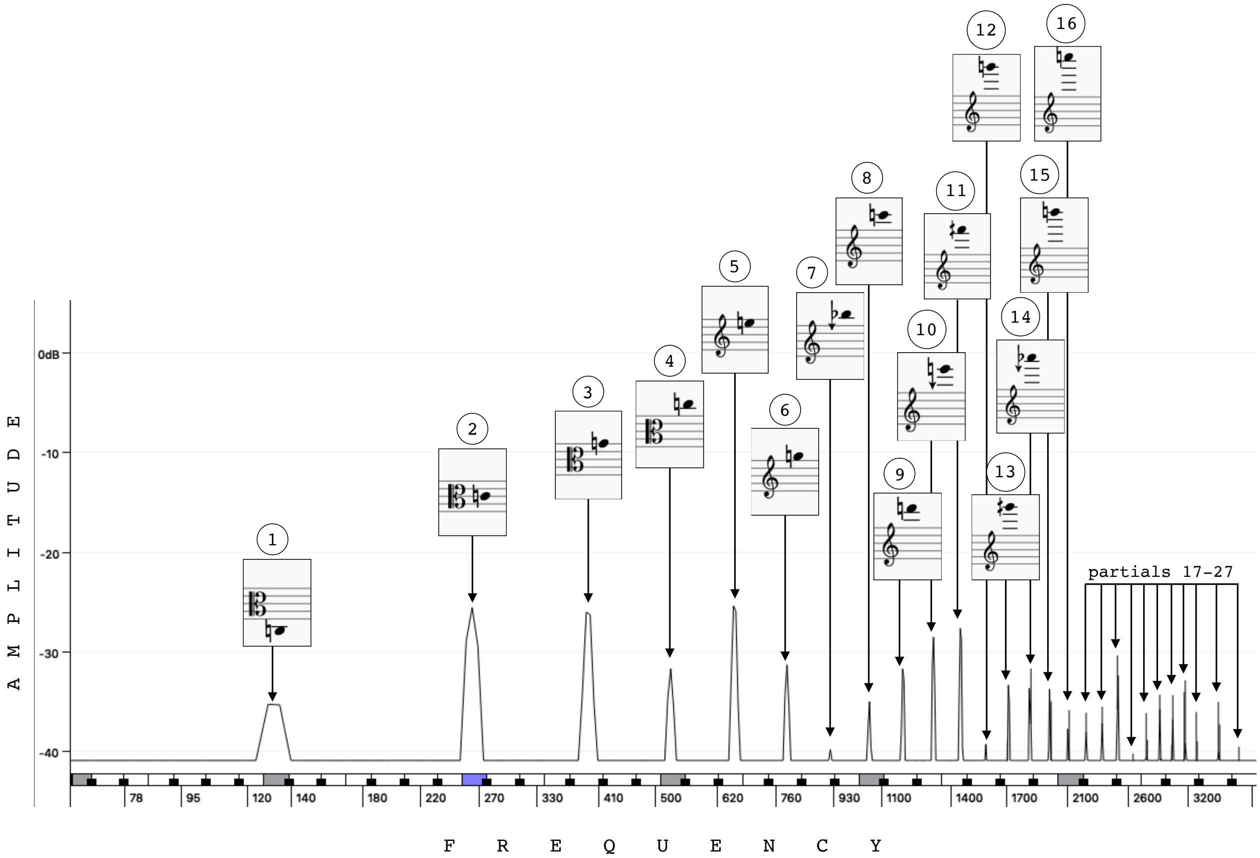

Figure 1. Spectrogram analysis and partial series at one moment in time of bowed open C String[1]

With the advent of the computer analysis and synthesis of sound, composers in the 1960s and 70s, most notably Jean-Claude Risset (1938-2016) in the domain of computer music, then Gérard Grisey (1946-1998) and Tristan Murail (1947-) in the domain of instrumental music, began to mine the spectral content inside of individual sounds for the source of compositional inspiration. Their discoveries and the artistic application of those discoveries in compositional contexts have helped to re-shape our understanding of musical sound and forge new futures for instrumental performance.

3. The Harmonic Series

Before the computer analysis of sound spectra was possible, physicists Georg Ohm (1789-1854) and Hermann von Helmholtz (1821-1894) showed that periodic sounds, those sounds which contain a clear pitch and which we often imprudently call "musical sounds", contain a spectrum of harmonic partials

[1] There is as yet no standard notation for the microtonal deviations present in either the harmonic series or naturally occurring partials. This is evidenced by the fact that the three pieces analyzed in this article all use different notational strategies. In this article, I have opted to use the nearest 1/8th note approximation, following Grisey's notation. This uses standard quarter-tone accidentals plus arrows pointing up or down to indicate deviations of an 1/8 tone. Circled numbers throughout this article indicate partial number in ascending order.

whose frequencies equal the frequencies of the harmonic series[2], known to string players as the natural harmonics. Compare the natural harmonics of our open C-string below with the spectral content of the bowed open C String as revealed above in Figure 1.

Figure 2. The harmonic series of the C string

As violists, we can test their discovery easily by alternating bowing a loud, rich tone on the open C string with any of the natural harmonics on the same string. When we go back to playing the open string we can hear the pitch of the previous natural harmonic ringing within the full sound of the open C string tone.

From the perspective of physics, it is no surprise that the naturally occurring harmonics of an open string are equal to the partials of a harmonically rich tone produced on that same open string. Our strings vibrate back and forth physically in a harmonic motion. Not only do they vibrate at the frequency of the sounding pitch, they are simultaneously vibrating at the frequencies of all of the subsequent partials - or *overtones* - of the harmonic series. By lightly touching the vibrating string along one of the nodes of this harmonic vibration , we are able to isolate both the physical and the acoustic harmonic partial.

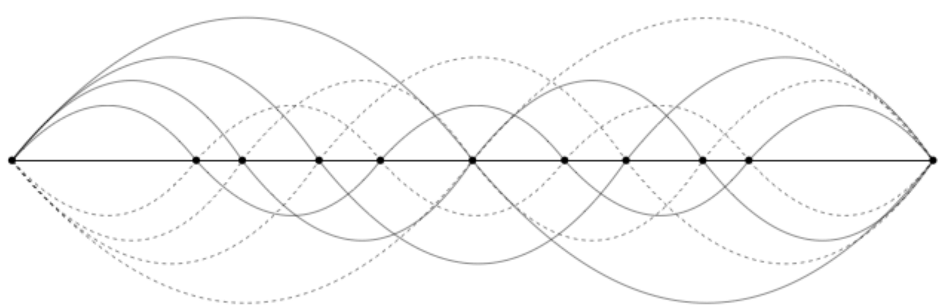

Figure 3. Physical harmonic motion of a vibrating string (partials 2-5).

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[2] Mathematically, we can define the harmonic series as one in which the frequency of each partial is equal to a whole number multiple of the frequency of the sounding fundamental tone. Thus, for any note of frequency *f*, the frequency of the first partial $F(P_1)$ is equal to $1*f$, $F(P_2)=2*f$, $F(P_3)=3*f$, $F(P_4)=4*f$, $F(P_5)=5*f$, and so on and so forth, such that for any P_x, $F(P_x)=x*f$. This series is known mathematically as the Fourier Series, named after its discoverer, the french mathematician and physicist Jean-Baptiste Joseph Fourier (1768-1830).

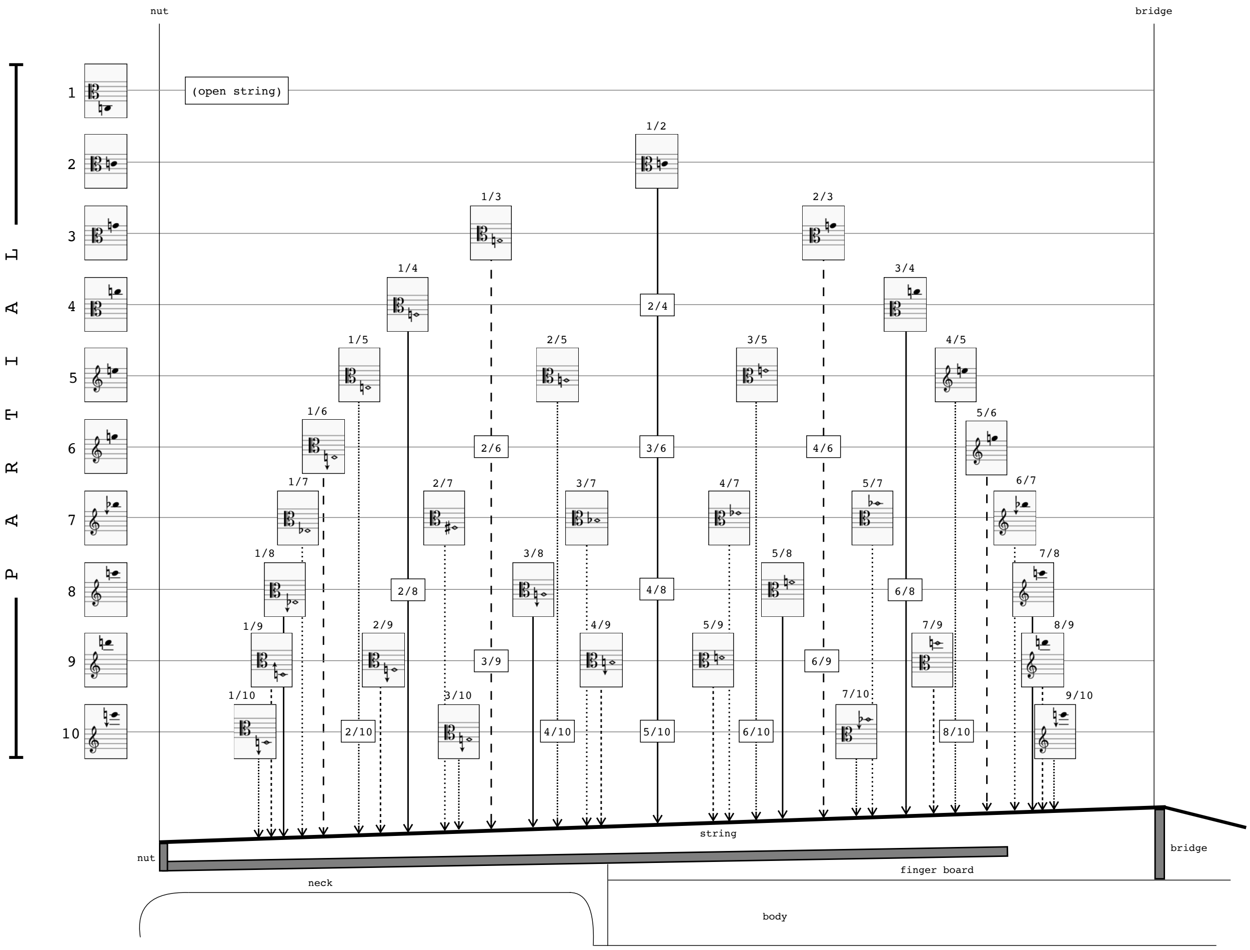


Figure 4. Physical location and sounding pitch of natural harmonics on the C string

4. Horaţiu Rădulescu: *Das Andere*

Music based on the harmonic series can be found in many of the traditional musical cultures across the world, such as in the music of Swiss Alphorns or Mongolian throat singing. Composers have long used natural harmonics as an instrumental effect in their works, from Paganini to Stravinsky; however, it was not until Horaţiu Rădulescu's ecstatically abrasive *Das Andere* (1984) for solo viola[3] that the upper reaches of natural harmonics playing were opened up to future generations of violists.

The 18 minute piece consists of large blocks of high harmonic playing alternating with sections of arpeggiated harmonies derived using ring modulation played in the lower positions across all four strings. The high harmonics are played across two strings at a time, creating "very irregular melodies

[3] Technically, *Das Andere* was written for "a string instrument tuned in 5ths", but since the work was written for the french violist Gérard Caussé and utilizes the alto clef, we can claim it as originally for our own.

resembling high alphorns". When the high harmonics of two strings sound simultaneously as a double stop, they create low differential sounds or *difference tones*, marked δ in the score. The work starts with almost three and a half minutes of high harmonics on the A and D strings. After a section of ring modulated harmony, the high harmonics come back on the D and G strings, then again later on the G and C strings, giving the work a global downward motion over the course of the piece before culminating dramatically in "bowed harmonics" on the open C string at the end.

Whereas almost all earlier harmonic writing was restricted to the first 8 partials, Rădulescu expands the range upward to reach the 20th partial. Immediately, we are confronted by extreme high pitches which lie well beyond our normal staff and the non-tempered tuning of the harmonic pitches (most noticeably in the pure 3rd of the 5th partial, the flat 7th partial, and the 1/4 tone 11th partial). In order to simplify matters, Rădulescu replaces traditional pitched notation with a graphic system that represents each string with a horizontal line and each harmonic with a number.

Figure 5. Harmonic notation in *Das Andere*

This notation allows Rădulescu to create a pillow of improvised biphony, marked Σ followed by the numbers of harmonics utilized in a given section, from which double stopped melodies arise (marked |/ and |\ with numbers indicating harmonics to be played). Each "beat", marked by the dotted lines, lasts 2 seconds. Each measure, marked by the solid black lines, lasting 10 seconds.

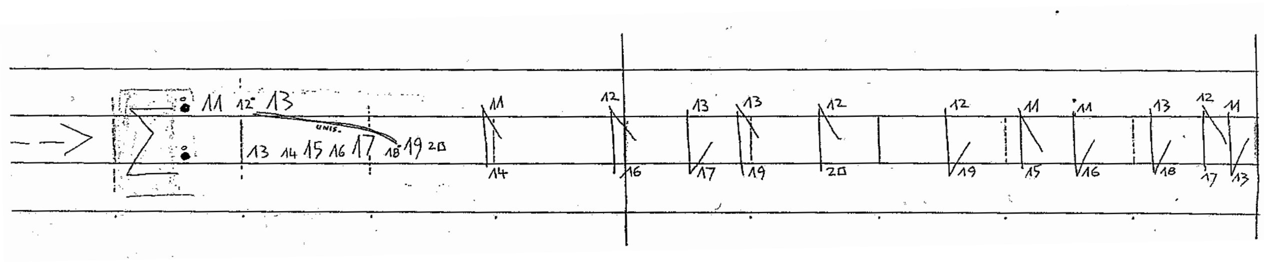


Figure 6(a). Horațiu Rădulescu, *Das Andere*, bottom of page 12

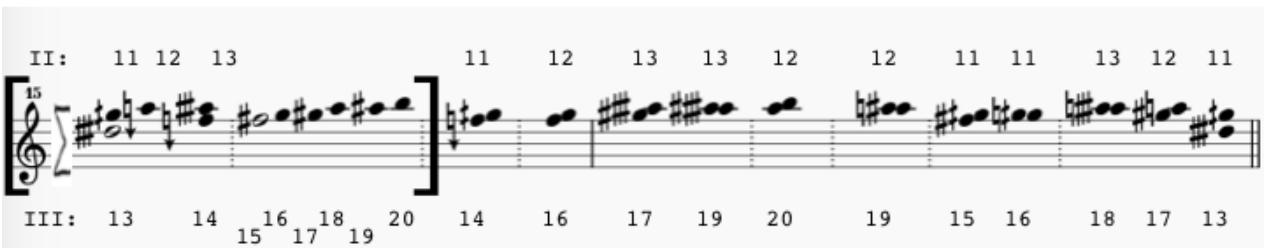


Figure 6(b). Transcription of Figure 5(a)

While at first sight Rădulescu's notation may seem an unwelcome divergence from tradition, the violist is quickly able to learn the sound of each partial such that playing by numbers becomes significantly easier than playing by pitch notation. In order to learn the pitch material, the violist is encouraged to play harmonic scales and "arpeggios" on each string, followed by testing whereby a number 1 through 20 is randomly selected and the corresponding harmonic is immediately played.

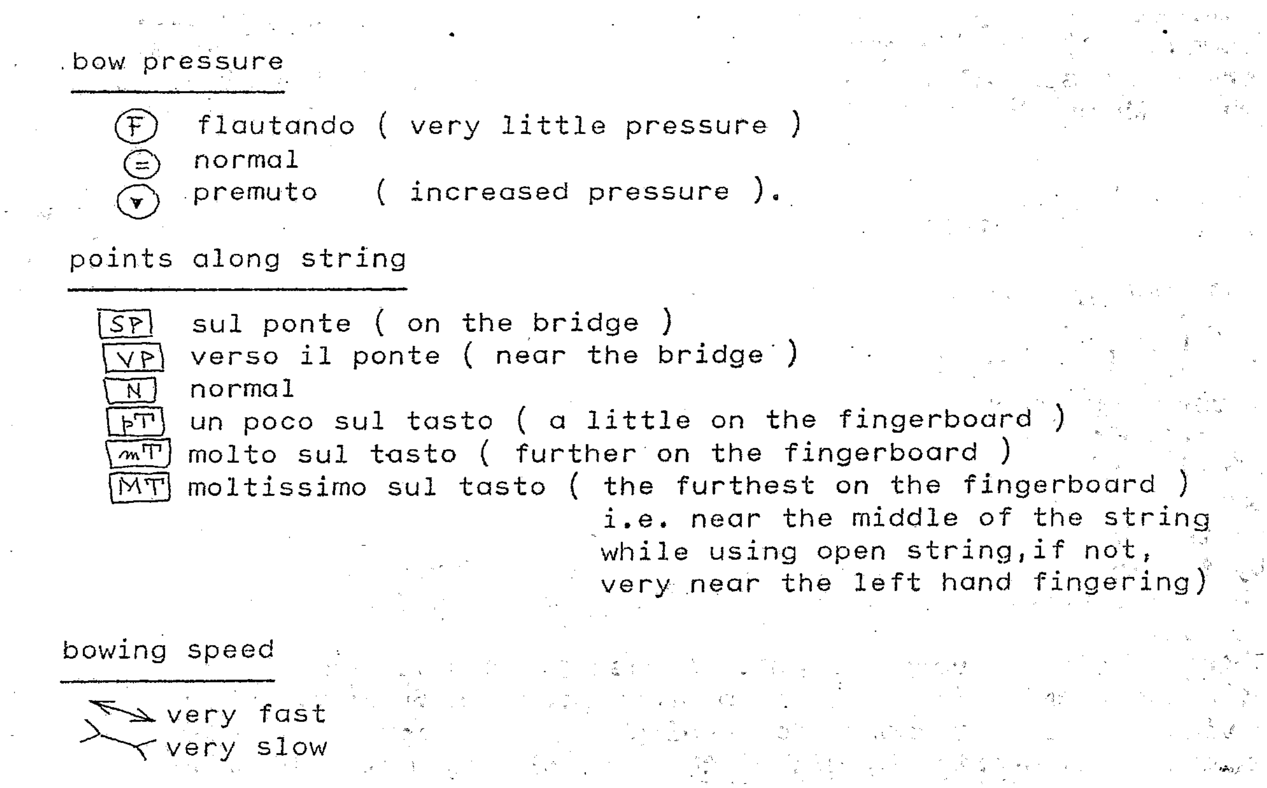
Figure 7. Natural Harmonics 1-20 on all four strings, as used by Horațiu Rădulescu in *Das Andere*

Once the harmonic series has been learned, it is a quick jump to understanding each Σ section and having the "colliding" pitch melodies planted firmly in the ear.

In addition to playing extreme harmonic partials directly with the left hand, Rădulescu utilizes four other techniques to create spectral harmony.

1] <u>Bowing Techniques</u>

By changing bow pressure, contact point, and bow speed, the bow becomes a filter for spectral content. Playing *sul ponticello* highlights the upper harmonic partials, creating a sparkling or crystalline sound. Playing *sul tasto* depresses the upper overtones making a hollow sound consisting only of the lowest harmonic partials. Rapid shifts and changes allow the violist to create dynamic spectrums that shift the spectral content within individual notes, creating the possibility of picking out specific partials or building complex, shifting textures.


bow pressure

F flautando (very little pressure)
= normal
▼ premuto (increased pressure).

points along string

SP sul ponte (on the bridge)
VP verso il ponte (near the bridge)
N normal
pT un poco sul tasto (a little on the fingerboard)
mT molto sul tasto (further on the fingerboard)
MT moltissimo sul tasto (the furthest on the fingerboard i.e. near the middle of the string while using open string, if not, very near the left hand fingering)

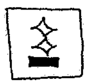
bowing speed

very fast
very slow

Figure 8. Bowing indications in Horațiu Rădulescu: *Das Andere*

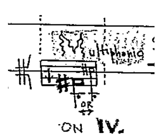
2]  " 'u du 'u du " bowing, aka phase shifting arco

This technique consists of bowing with *flautando* pressure and a very fast bow speed with quick bow changes, sliding up and down at different contact points along the string (shifting contact point only during bow changes, not during the horizontal drawing of the up or down bows). This combined action creates a complex texture consisting of the fundamental; a white noise or "breathing sound" caused by the disengaged bow hair sliding across the string; high overtones which speak during the bow changes, shifting up and down the harmonic series with the shifts in contact point; and a low " 'u du 'u du " rhythmic sound for which the technique gets its name, a " 'phantom' rhythm of shifting ONSET/MUTING" as Rădulescu puts it.

3] 

"Little Devils"

A kind of spectral dust created by bowing quasi and *sul ponticello* with *flautando* bow at the same time as the harmonic finger of an artificial harmonic slides back and forth near the stopped finger. As we saw in *figure 3*, natural harmonics exist symmetrically along the string. We can play the 3rd, 4th, 5th, 6th and 7th harmonics easily in 1st position as well as at the upper end of the fingerboard. A so-called "artificial" harmonic is nothing more than a natural harmonic in which another finger (usually the index) shortens the string length in order to create a new fundamental. The little devils technique picks out the extreme partials, 7th through 20th, of the given fundamental by fingering them in their inverted position near the stopped string. NB the technique of playing harmonics is as much a question of bow usage as it is the proper placement of the left hand fingers. The use of flautando pressure and shifting contact point close to the bridge helps to bring out a richer gamut of partials.

4] 

Multiphonic Sound

Here the left hand touches the string lightly as with a natural harmonic, but at a point between two harmonic nodes (Rădulescu asks for the augmented fifth or the minor tenth, but we can find other locations for this technique as well). With the bow at a slow speed and increased pressure at a proper contact point, we can produce a complex mix consisting of a reduced number of harmonic partials[4]. The resulting sound is similar in quality to the sound of a ring modulated tone in electronic music or an oboe's multiphonic sound.

5. György Ligeti: *Viola Sonata - I. Hora lungă*

With the first movement of the Ligeti *Viola Sonata*, *Hora lungă*, we pass from music performed by playing natural harmonics to the use of the harmonic series as a model for pitch material.

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[4] The contact point here is a function of the string and instrument physics of each individual viola set-up. It is therefore different for each multiphonic sound and each string/instrument combination. Composers wishing to use multiphonics should be aware that what works for one instrument may not work universally.

Ligeti was interested in microtonality well before his compositions of the 1980s and 90s (see for instance *Ramifications* (1968-69) for two groups of strings tuned an 1/8th tone apart); however, it was not until contact with the music of Harry Partch (1901-1974), Claude Vivier (1948-1983), and his student Manfred Stahnke (b. 1951) that Ligeti began to use natural and spectral tuning systems. The viola scordatura part in the first movement of the *Violin Concerto* (1989-1993) — the piece from which the viola sonata grew - is built almost entirely from running scales of natural harmonics across all fours strings. Later, in the *Hamburg Concerto* (1998-1999/rev. 2003) he used natural horns to create harmonies from pitches of the harmonic series.

Ligeti tells us "I imagined that the viola has an F string one fifth lower, which doesn't exist in reality and which the fifth, seventh and eleventh harmonics would be natural pitches, which sound "false" in the tempered system"[5]. Whereas Rădulescu was able to avoid the issue of microtonal notation for the harmonic overtones which are "out of tune" with the tempered scale, Ligeti was forced to confront the problem head-on with his need for regularly stopped notes that model a harmonic series of a string which does not exist. Consequently, he developed a unique and useful system of three accidental alterations:

↓ 5th harmonic 14 cents lower tempered major 3rd	↓ 7th harmonic 31 cents lower ~ 1/6 tone	↓ 11th harmonic 49 cents lower ~ 1/4 tone

Figure 9. Accidentals in György Ligeti *Viola Sonata - I. Hora Lungă*

Hora Lungă is performed entirely on the C String and consists of six expanding iterations of a simple folk-like melody, punctuated by a short interlude and a coda both exclusively using the natural harmonics of the C string. The harmonic material is comprised of pitches from the natural harmonic series of F and C, one questionable note either from the D harmonic series or a justly tuned major third, and non-harmonic tempered notes. This creates a complex "mixing" of tempered and harmonic tuning, similar to that found in the first movement of the *Violin Concerto* where the natural harmonics of the scordatura violin and viola parts clash with the tempered tuning of the solo violin and ensemble.

5 György Ligeti, *L'atelier du compositeur,* edition contrechamps, 2013

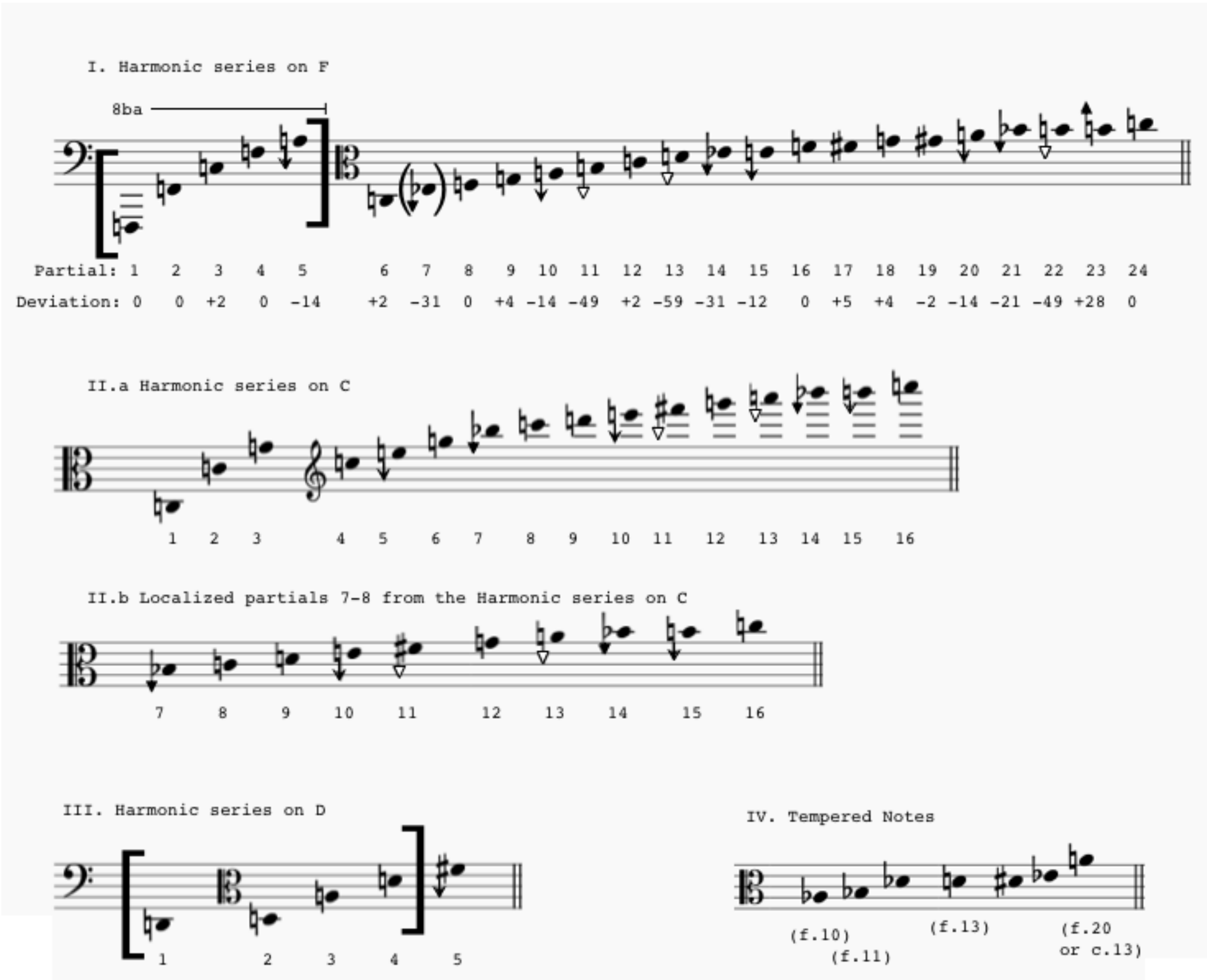

Figure 10. Harmonic material of György Ligeti *Viola Sonata - I. Hora Lungă*[6]

The melodic material is then derived from two scales, mixing "spectral" notes from the harmonic series and tempered "inflections". In both cases, the scale on F and the scale on C, the 13th overtone is inflected upward into tempered tuning. The questionable flat F# in measure 20 can either be considered the fifth overtone of the D series or an inflected 17th harmonic of the F series tuned justly with the tempered 13th D natural.

[6] The deviation marked beneath the partial numbers of the harmonic series on F show the distance from the nearest tempered not in Cents (1/100th of a tempered half step).

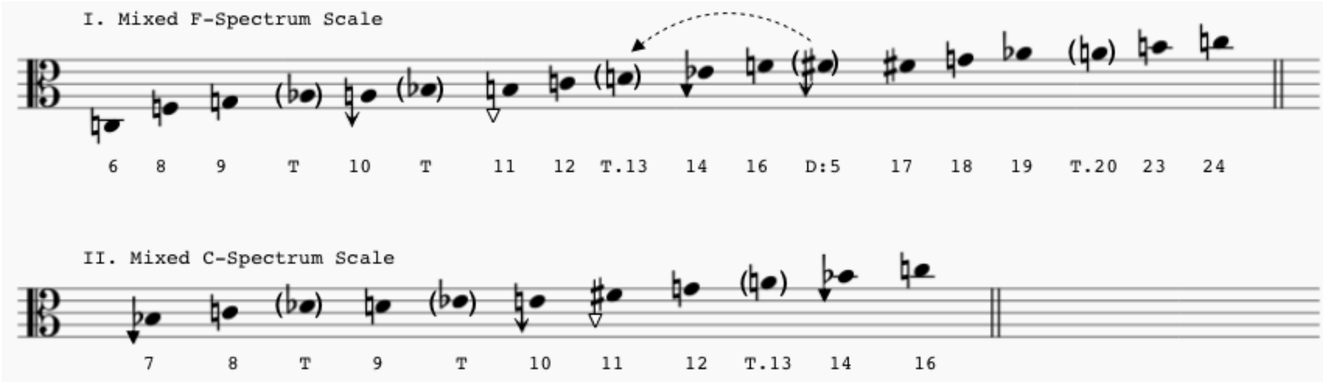

Figure 11. Two foundational scales of György Ligeti *Viola Sonata - I. Hora Lungă*

The key to properly performing the intonation of *Hora Lungă* lies in, as with all music, building a proper understanding and hearing of the function of each note rather than aiming for ambiguous "out of tune" microtonal notes. By comparing the score with the two foundational scales above, the violist can identify the exact function of each pitch in the piece. What becomes quickly apparent is that each iteration increases the number of pitches used as well as the complexity of the harmonic/tempered mixture. This shifts the ratio of harmonic pitches to non-harmonic pitches with each iteration, in other words, increasing harmonic complexity over the course of the piece (the gradual increase of complexity is the core structural law governing the entire sonata). What's more, there is a key shift from the Mixed F-spectrum Scale to the Mixed C-Spectrum Scale at the most dramatic moment of the piece at the high FFFF C in the middle of measure 29. The violist can practice hearing the pitches by retuning the C string to a low F and playing harmonics, or by testing with a synthesizer tuned to the various pitches used throughout the piece.

6. Spectral Analysis

The two examples analyzed above show composers exploring spectral harmony through the use of the harmonic series. In the case of Rădulescu and the interlude and coda sections of Ligeti, the natural harmonics offer a clear way to directly play the harmonic partials of a fundamental. In *Hora Lungă*, Ligeti uses the theoretical calculation of an overtone series as a model for pitch material of normal, stopped notes. However, these are not the only ways we can explore spectral harmony. One of the key developments of early spectral composition was the use of computers to analyze the spectral content of sound.

The spectrogram analysis in example 1 showed us the spectral content of the healthy, bowed open C string at one moment in time. However, we can go even further by graphing out the frequency distribution of the tone over time and increasing the sensitivity of the frequency measurements.

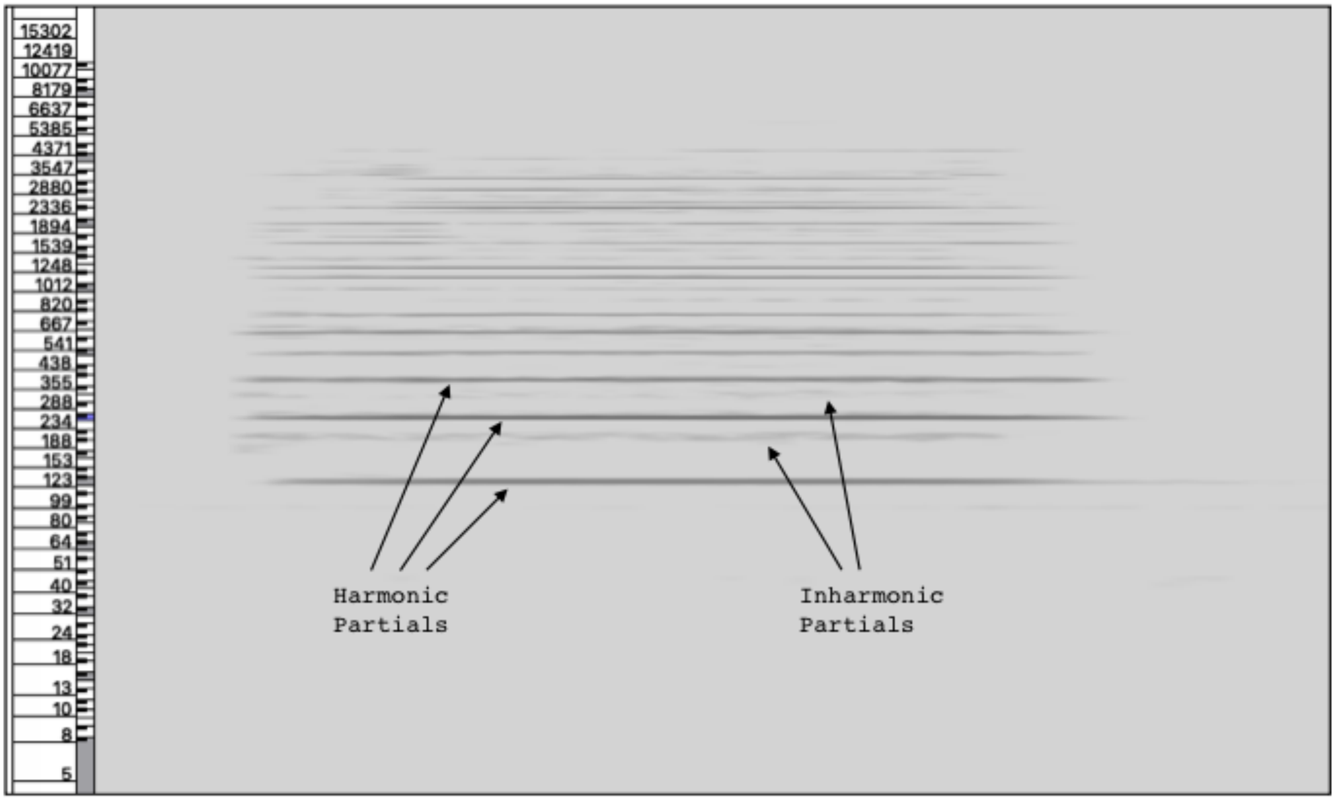

Figure 12. Spectrogram image showing frequency distribution over time of bowed open C String

What is immediately evident is that there are high levels of energy at frequencies 130HZ, 260HZ, 390HZ, 520HZ, 650HZ, etc… all corresponding with the natural harmonics of the C string. However, there is also energy at frequencies not corresponding with the harmonic series. These other, barely audible partials help fill the sound with a soft cushion of noisy dust, adding to the overall character of the viola sound.

We can distinguish two kinds of partials: 1) *harmonic partials* which occur in the harmonic or Fourier series; and 2) *inharmonic partials* which do not occur in the harmonic series.

Not all inharmonic partials are equal, however. Partials can be compared using their *degree of harmonicity*, or the distance from the frequency of the nearest harmonic partial. In the analysis above, a partial at frequency 260HZ would have a harmonicity of 1 since it corresponds exactly with the 2nd harmonic of the fundamental, 130HZ. A partial at frequency 263HZ (which is close but not perfectly in tune with the 2nd harmonic) would have a harmonicity of 95.4%, whereas a partial at frequency 325HZ would have a harmonicity of 0.00% as it lies exactly equidistant between the second and third harmonic partials.

Just as harmonicity can be used to to describe partials of a given spectrum, we can describe musical chords or pitch sets as having different degrees of harmonicity, even going so far as to measure the harmonicity of a collection of notes.

Figure 13. harmonic and inharmonic chords built on C2

When we begin to think of partials as notes, the idea of traditional harmony begins to be redefined. If we have a different instrument play each note of the harmonic chord above, a technique Grisey called *instrumental additive synthesis*, is the result a chord or a single note with rich spectral content? Can we consider a single note, such as I played on the open C string for the analysis of *Figures 1 and 11*, as having its own rich complex harmony rather than being "just a single note"? The continuum from pure harmonicity to complete inharmonicity can serve as a more nuanced approach to understanding consonance and dissonance, with harmonicity replacing consonance and inharmonicity substituting for dissonance. In addition to distance from harmonic partials, it should be noted, the degree of harmonicity is weighted such that lower overtones are more "harmonious" or consonant than higher overtones[7].

Another way of studying the spectral content of a sound is to look directly at the sound wave itself, measuring the changes in air pressure over time at one specific location. The sound wave of the open C string analyzed above is shown in Figure 14. Each grey boxes shows one period. While the overall shape is, on first glance, complex, it is periodic. The basic form of the sound wave repeats over and over again, approximately 130 times per second, over the course of the tone,.

[7] This spectral conception of consonance and dissonance is in line with Arnold Schoenberg's teachings in the *Theory Of Harmony*, in which he defines "consonances as the closer, simpler relations to the fundamental tone, dissonances as those that are more remote, more complicated" (Schoenberg, *Theory of Harmony*, 25)

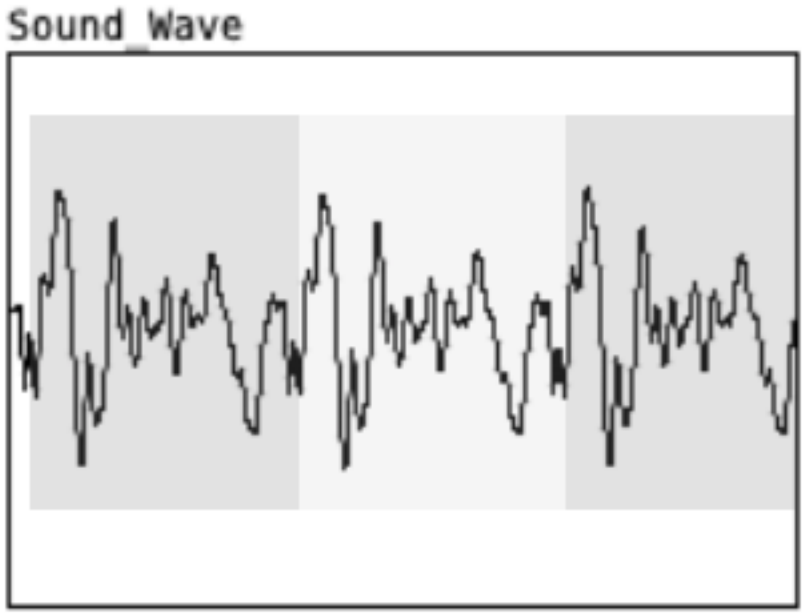

Figure 14. Sound wave of an open C string

Using a mathematical tool called the Fourier Transform we can break apart the complex wave above into a series of simple waves, each with just one frequency.

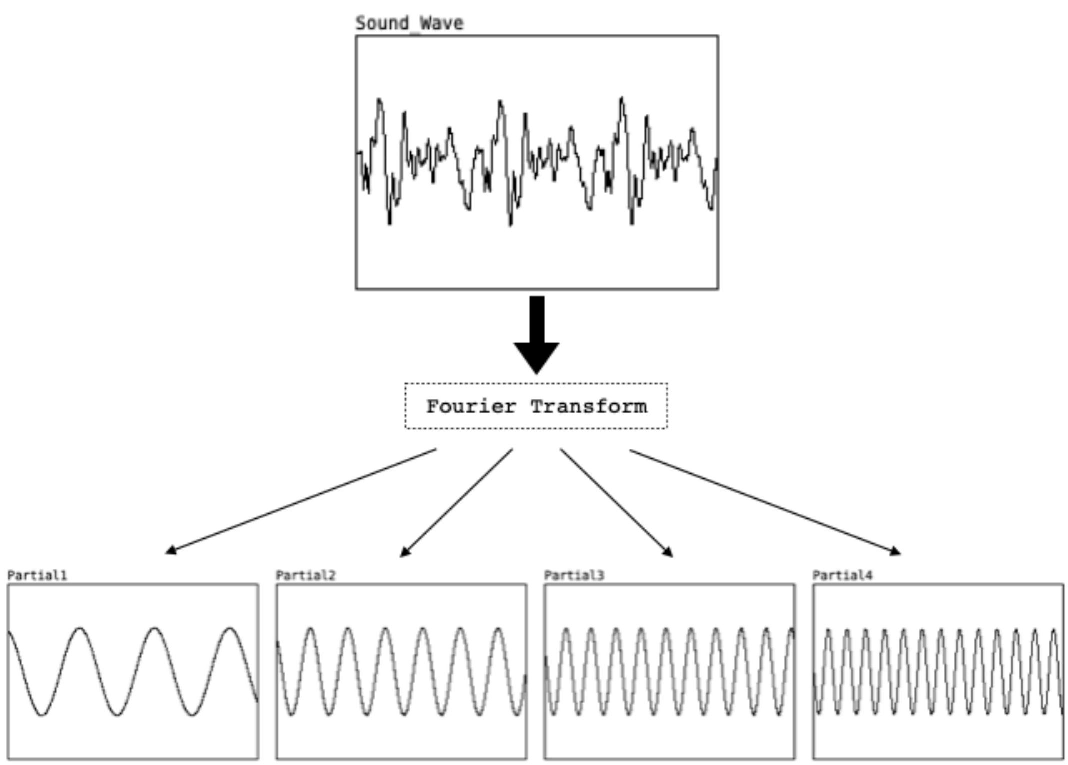

Figure 15. Fourier transform turning open C string sound wave into component waves

The simple sounds above represent frequencies with no spectral content, a sound which is theoretical for the purpose of analysis but can be created using the techniques of electronic music synthesis in the form of a *sine wave*. Sine waves are the most basic units of sound, the atoms of sound according to Stockhausen. They contain no spectral content, no richness, no color, almost no timbre, just pure tone.

On the opposite extreme of the sound wave lies pure noise, defined properly as a completely saturated sound whose spectral content includes an equal distribution of all possible frequencies occurring simultaneously. If we were to do a frequency analysis of a pure noise using the technique in *Figure 14*, the resulting image would be completely black because all frequencies would be present. We can visualize a continuum of sound waves lying between pure noise and the pure tone of a sine wave. Pure noise is a wave which is completely irregular, or *aperiodic*, whereas pure tone is totally regular, or *periodic*.

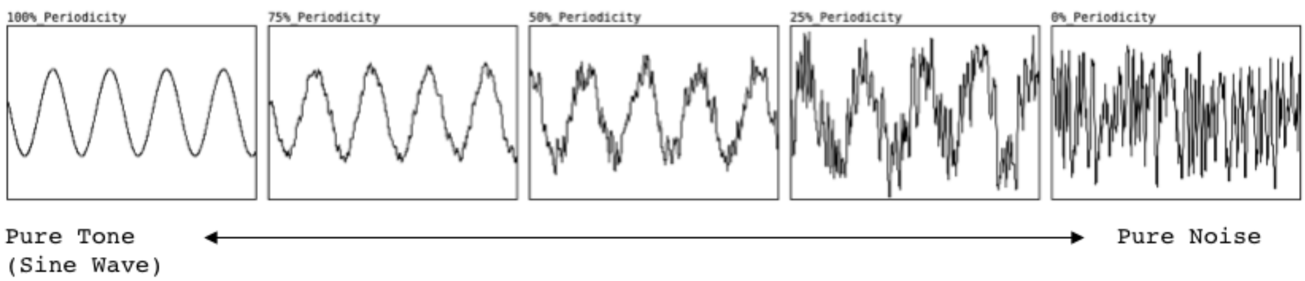

Figure 16. Noise-tone continuum

Through the use of computer analysis we can break apart sounds, looking under the hood and analyzing their spectral content with all its inherent messiness. What becomes quickly apparent when analyzing naturally occurring acoustic sounds is that there is no such thing as pure tone and pure noise. All sounds contain a certain amount of tone and a certain amount of noise. Sounds like scratches, percussive hits, bowing on the bridge or the body of the instrument have a high noise content but still contain a certain modicum of regularity. Pure sounds like harmonics or high notes on the A string have very little noise, very little spectral content, but still contain a small level of irregularity. All sounds lie between pure noise and pure tone, absolute irregularity and absolute regularity. They are *quasi-periodic*.

<u>7. Gérard Grisey: *Prologue*</u>

Gérard Grisey's monumental *Prologue* (1976) for solo viola, with or without electronics, is built around the gradual movement from harmonicity to inharmonicity, from tone to noise. The main section, consisting of the first three pages of the score, makes use of three main elements: 1) melodic motifs, referred to as Gestalt or neumes, built using discrete pitches which gradually morph into continuous glissandi[8]; 2) a simple heart beat gesture, echoing in a sense the heart beat gesture of Tristan Murail's "...c'est un jardin secret..." for solo viola, which evolves into noisy, granular ricochet and crushed tone gestures; and 3) "échos" or played resonance which hangs on and evolves at the end of each melodic gestalt. The gestalts themselves increase in complexity over the course of the first section, including more and higher pitches, always in different orders, and becoming more and more inharmonic as the process carries the piece towards its climax. Rhythmically, in a kind of biological hybrid between traditional and time-space notation, the gestalts contain a microcosm of the entire structure, first moving from slow to fast within each gesture until reaching a mid-point where they start to spin in reverse from fast to slow.

Prologue was designed to be both a stand alone work and the opening of an evening length cycle of six pieces known as *Les Espaces acoustiques* (1976-1985). The cycle consists of *Prologue* for solo viola (1976) - *Périodes* for 7 musicians (1974) - *Partiels* for 16 or 18 musicians (1975) - *Modulations* for 33 musicians (1976-1977) - *Transitoires* for orchestra (1980-1981) - and *Épilogue* for orchestra and four horn soloists (1985). Each piece explores a different acoustic phenomenon and can be thought of together as a kind of art of spectral composition, containing the core ideas of Grisey's early compositional thinking. *Prologue* focuses on resonance[9], the idea of harmonicity, and perceptual gestalts. The entire cycle makes significant use of the harmonic spectrum of a low E, incorporating multiple spectral analyses of the low E as played on Trombone and double bass using various such as *arco ord.*, *arco ponticello*, *arco sul tasto*, *pizz. ord.*, *pizz. pont.*, *pizz. sul tasto*, and the gradually passage between *tasto* and *ponticello*[10].

What is most stunning and, at the same time, most daunting to the violist wishing to perform *Prologue* is Grisey's subtle use of pitch to create the motion from harmonicity to inharmonicity. This requires the violist to be able to play microtonal intonation as fine as 1/8th of a tone and, as with the Ligeti *Sonata*, have a proper understanding of the function of each note in order to understand which notes are harmonic partials and which are inharmonic.

The melodic gestalts make use of the harmonic partials 3 through 34 of the low E, plus "tempered" approximations of partials 36 and 38 (see figure 15). Following the first gesture, which makes use of partials 3 through 9, each partial is introduced successively in order, creating a gradual rise in the top range of the melodic gestalts as the piece develops. This process breaks down into a tempered

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[8] For an extensive analysis of the melodic lines in *Prologue* see Jérôme Baillet, *Gérard Grisey: Fondements d'une écriture*, L'Itinéraire, 2000

[9] *Prologue* was originally written with the violist playing directly into different amplified "resonators", like a piano or snare drum, in order to alter the sound. This idea was later reworked into the live electronics part which processes the viola sound through synthetic resonators simulating the original acoustic resonators.

[10] See Dufourt, 359-60

chromatic scale from F# to F-natural in the top range of the viola during the final glissandi before total inharmonicity is reached in the scratching climax.

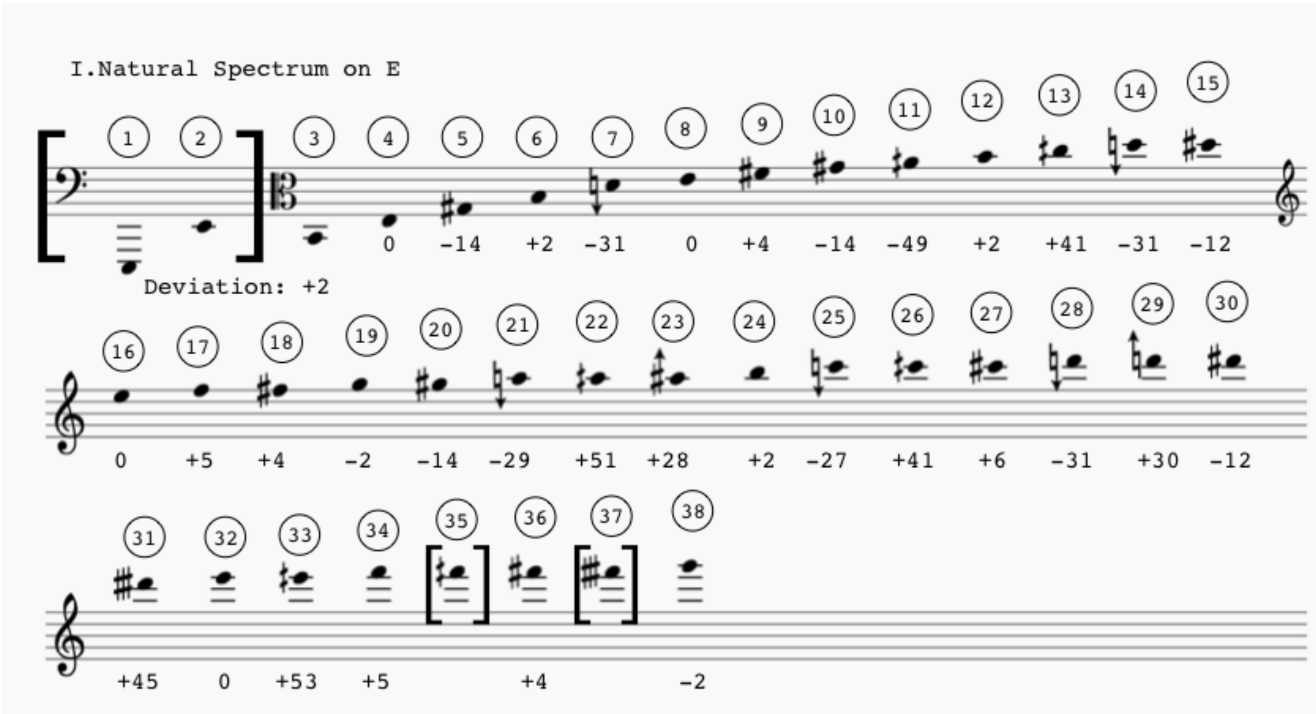

Figure 17. Natural harmonic series on E as used in *Prologue*

As the melodic gestalts continue to grow in length and range, individual pitches from the gamut are transformed one by one into inharmonic pitches. For instance, the 4th partial E rises to a tempered F-natural, then later again to an F#. Once a partial has been altered it always returns in its altered state unless it is altered again further, as is the case with the 14th partial which goes through three rising altered notes.

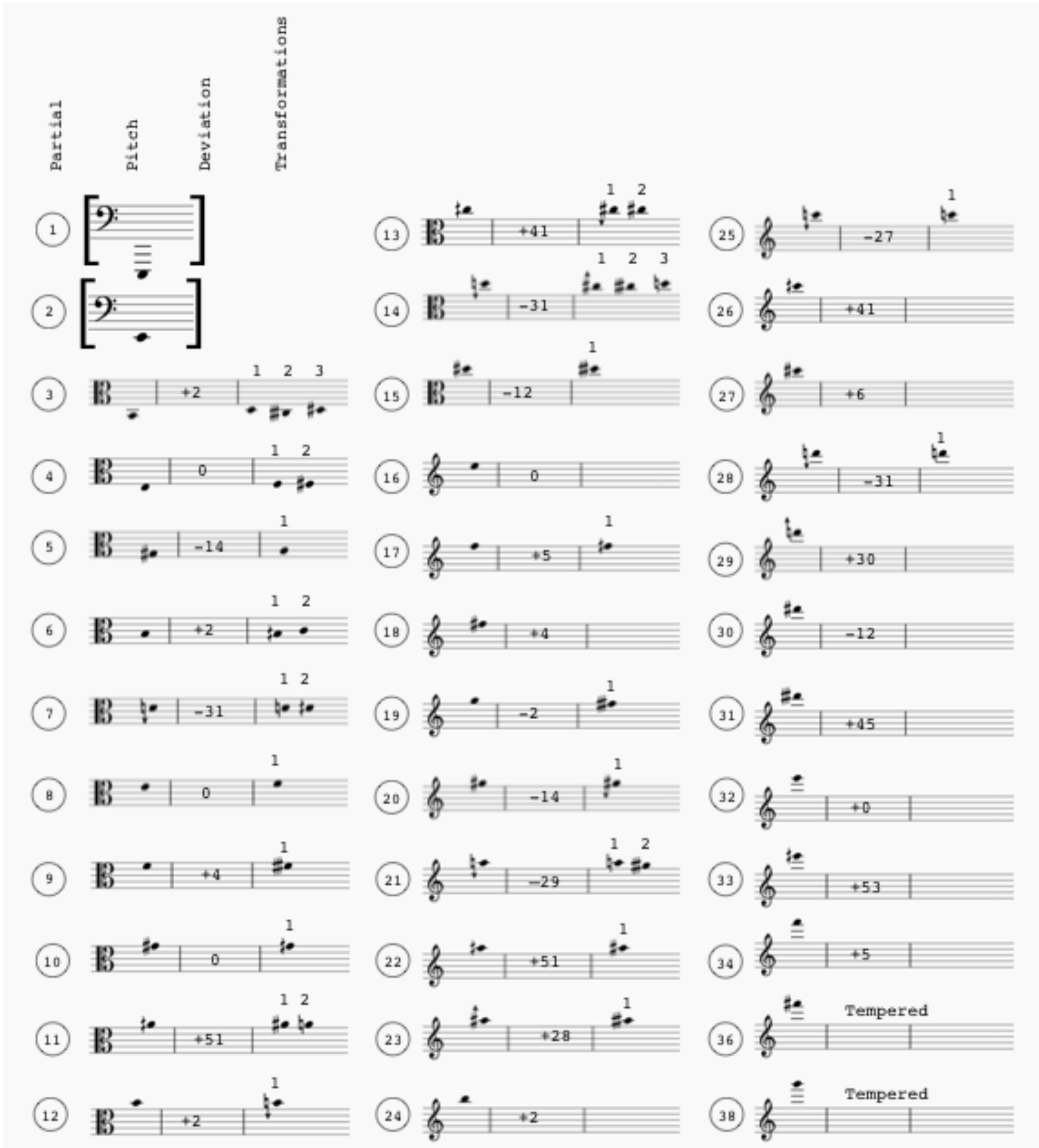

Figure 18. Transformations of the E spectrum in *Prologue*

The final result is an altered inharmonic spectrum that then explodes into pure noise.

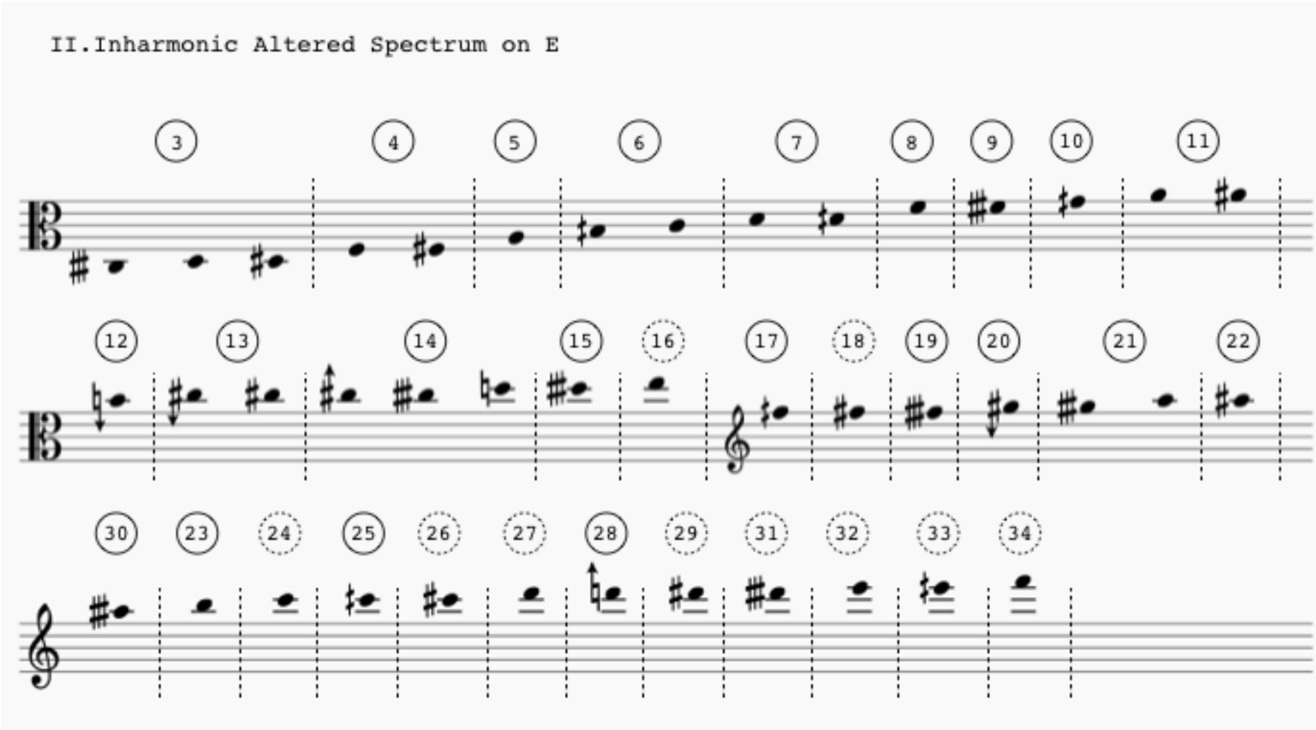

Figure 19. Altered inharmonic spectrum in *Prologue* (partials marked with dotted circles are unaltered throughout the piece)

As with Ligeti, in order to properly hear the subtlety of Grisey's harmonic evolution, the violist must have a firm understanding of the function of each note. The violist can use the charts above to identify each note in the score as being a given harmonic partial or an inharmonic transformation, even going so far as to write each note function directly into the score. Through this analysis the entire harmonic process moving from harmonicity to inharmonicity reveals itself, both visually on the score and to the ear. More than simply knowing the function of each note, this rewriting allows the violist learning *Prologue* to learn the spectral harmony by ear with the aid of a synthesizer tuned to either the natural harmonic series of E or the altered inharmonic spectrums later on.[11]

<u>8. Conclusion</u>

The use of the spectral content as a model for harmonic material is one of the key developments of western composition over the past half century. As violists, we are fortunate to have three of the most important solo string works using spectral harmony written for our instrument. The three works analyzed above show three different approaches toward spectral harmony: 1) playing natural harmonics (Radulescu and Ligeti); 2) mixing the harmonic series with tempered notes to create synthetic scales (Ligeti); and 3) shifting the harmonicity of an overall set of notes by modulating harmonic partials into inharmonic notes (Grisey). All of these approaches can be considered *macrophonic* approaches in that they treat harmony on the large scale of the entire piece.

[11] This analysis and a simple synthesizer is available at [website…]

In addition to the above works, modern violists are sure to come across challenges posed by macrophonic spectral harmony over the course of their careers, whether in the works of the contemporary European avant-garde like Georg Friedrich Haas, Enno Poppe, and Kaija Saariaho, pieces by American experimentalists like James Tenney, Pauline Oliveros, Alvin Lucier, and La Monte Young, or in compositions by student and young composers of the next generation.

Regardless of the context, the violist can equip themselves by the model set forth above. This includes 1) developing a strong understanding of the harmonic series through extensive study of the natural harmonics; 2) incorporating the use of computers in practice, either through the development of specially tuned synthesizers (as I have done for Ligeti and Grisey) or through the computer analysis of sound; and 3) carefully analyzing works in order to conceptually and aurally understand the pitch function of each note in a piece.

What we have explored above can be summed up as the use of timbre analysis as a model for harmony. In the next paper we will explore the opposite: how harmonic thinking can effect timbral thinking, moving from the macrophonic level to the microphonic level of the harmony within individual notes.