Spectra as Theoretical and Practical Models in Gérard Grisey's Creative Process

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Abstract and Keywords

Combining sketch studies, musical analysis, and acoustic analysis, this article examines the impact of spectral models on Grisey's creative process in the 1970s. First, it focuses on Grisey's establishment of initial theoretical models in *Dérives* and *Périodes*, composed during his residence at the Villa Medici (1972–74), during which period he conducted his own study of acoustics. The article then looks at how, back in Paris, the composer started studying with the acoustician Émile Leipp and then worked with Michèle Castellengo, with whom in 1977 he undertook for the first time the spectral analysis of instrumental sounds. Finally the article examines in detail how some spectrograms, once transcribed, were used in *Modulations* (1976–77) to construct a complex spectral polyphony. If Grisey draws his inspiration from sound phenomena and the characteristics of auditory perception, he does not for all that neglect structuralism: spectral models serve both to simulate natural phenomena and to formalise his compositional processes.

Keywords: Gérard Grisey, Michèle Castellengo, acoustics, spectrogram, spectral analysis, Les Espaces acoustiques, Dérives, formant

Introduction

The emergence of spectral music in the 1970s is closely related to the new mutations caused by the dissemination of knowledge in musical acoustics and the development of computer sound analysis/synthesis techniques. The spectral representation of sounds stimulated both scientific and musical research: according to Hugues Dufourt, "access to the microstructure revealed the hidden springs in what we commonly call the 'life of a sound'"[1]. Gérard Grisey started to explore the secrets of the life of sounds through his music at the beginning of the 1970s. The physical structure of sounds and the mechanisms of auditory perception appeared to his eyes as a new beacon for elaborating his own musical language. In this way, spectral models became an inexhaustible source of inspiration, serving to structure and formalise compositional processes as well as guiding the listener through the musical journey. If Grisey's language cannot be definitively limit-

ed to the use of spectral models, these are nevertheless a core element of his musical grammar and should consequently be addressed carefully. When and how did the composer start working with spectral models? How are these models elaborated? Do they come systematically from the transcription of instrumental sounds? Finally, what role do they play in the development of musical processes and what impact do they have on auditory perception? To address these different questions, we will mainly focus on *Les Espaces acoustiques*—the six-piece cycle started in 1974 and completed in 1985[2]—through which the composer laid the foundation of his language, taking into account the reality of listening while maintaining a high degree of structural organisation.

To examine Grisey's music it seems crucial to study his compositions following the poietic, neutral, and esthesic levels identified by Molino and theorized by Nattiez.[3] A genetic approach, based on sketch studies but also on interviews with his collaborators sheds light on the creative process and its evolution through the construction of the *Les Espaces acoustiques* cycle. The study of Grisey's archives held at the Paul Sacher Foundation in Basel are a precious source in examining the origins and the characteristics of his musical language. In addition, several interviews were conducted by the author with Grisey's close relatives and collaborators, including the acoustician Michèle Castellengo, who carried out many spectral analyses for him. Interviews with Castellengo and the study of her private archives helped us to understand how Grisey designed some of his spectral models. After focusing on the poietic process, scores lend themselves more easily to analysis, and technical elements given by Grisey himself in some of his writings[4] or Baillet in his book dedicated to the composer[5] become fully understandable. Temporal structuring and compositional processes used to gradually transform sound structures appear more clearly on the neutral level. There is increasing awareness of the very high level of structural organization in his music. Spectral models, for example, provide Grisey with a series of numbers which serve to formalise his language in a totally abstract way. However, they are also the reflection of an acoustical reality, bringing forth original sound structures which have to be addressed in terms of auditory perception. As Hasegawa reminds us: "There is often a significant gap between the theoretical structures produced by spectral compositional procedures and the perception of these structures by the listener; due to this gap, an account of a work based solely on a reconstruction of compositional procedure often fails to reflect a listener's experience of the work."[6] That is why the esthesic process should also be addressed. Because of their singular impact on the listener's perception, some of Grisey's sound structures have to be analysed with tools and methodology derived from acoustics.

To begin we will look briefly at how Grisey started working with spectral models and with acoustics during his artistic residence at the Villa Medici in Rome (1972–74). Contrary to his claim, it seems that no trombone sound served to establish the spectral model that is at the heart of the cycle *Les Espaces acoustiques*. After this, we will examine when and how Grisey resorted for the first time to authentic spectral transcriptions of instrumental sounds. Attention will be given to his links to the Laboratoire d'Acoustique Musicale, a French laboratory founded by Émile Leipp in 1963 dedicated to the study of musical sounds and auditory perception. We will then address Grisey's collaboration with Castel-

lengo, who was the source of the numerous spectrograms the composer used from 1977 on. Lastly, we will focus on the creative process of the fourth section of *Modulations* (1976–77) for thirty-three musicians, explaining how Grisey constructed a complex polyphony, building on the transcriptions of spectral analyses of brass instruments with different mutes. In this context we will examine one spectrogram that may have been taken as a compositional model and will discuss its impact on auditory perception.

The harmonic spectrum as both a natural and a structural model

First steps towards acoustics

Angelo Orcalli observes in his essay on spectral thought that spectralism's development is concomitant with the transition from industrial to information society, generating new research paradigms and exploring the concepts of energy and information.[7] Sound visualisation tools and analysis-synthesis computer programs provided new knowledge and new material which impacted music in an unprecedented manner. Spectralism may not have emerged without the mutations introduced as a result of the research in these interdisciplinary research fields. "Digital sound synthesis and processing enable the composer to compose the sounds themselves instead of merely composing with sounds,"[8] as Jean-Claude Risset always underlined following his first experiments in sound synthesis at Bell Laboratories in the mid-1960s.

In the early 1970s, while still studying in Olivier Messiaen's class at the Paris Conservatoire, Grisey seemed to endorse this maxim and started to explore the secrets of sound's inner life in an instrumental context. He was introduced to rudiments of the physics of sounds and electroacoustic processing at this time thanks to Jean-Etienne Marie who had just founded in the Schola Cantorum the *Centre International de Recherche Musicale*.[9] As shown by different researchers, Grisey started using spectral chords modelled on resonance and the harmonic spectrum from 1970 in pieces such as *Initiation* (1970) for baritone voice, double bass, and trombone,[10] *Vagues, Chemins, le Souffle* (1970–72) for two orchestras and amplified solo clarinet,[11] or *D'eau et de pierre* (1972) for two instrumental groups.[12] The chords are still written in equal temperament and only served as auditory reference points. It was only in 1972 that Grisey began to considerably tweak his models, which not only acted as auditory references but also as core elements for structuring his pieces.

During the summer of 1972, Grisey attended György Ligeti and Karlheinz Stockhausen's seminars at the Darmstadt International Summer Courses for New Music. According to Grisey's class notes,[13] the two composers described, among other things, how they resorted to acoustical phenomena in some of their works. Grisey's Darmstadt notes on Stockhausen focus on the latter's seminars on *Stimmung* (1968) for six unaccompanied amplified voices. The central element in this piece is a harmonic spectrum with a fundamental frequency of 57 Hz. While this pitch, located between A1 and B♭1, is too low to be

sung, it still remains the work's foundation: the six frequencies (114, 171, 228, 285, 399, and 513 Hz) that form the pool of notes sung by the performers during the entire piece correspond respectively to the 2nd, 3rd, 4th, 5th, 7th, and 9th harmonics of the spectral model. During his courses, Ligeti talked about the use of combination tones in his *Ten Pieces* (1968) for wind quintet and made reference to publications in the area of acoustics (Figure 1). Also present was John Chowning (invited by Ligeti), who, during a presentation of his research on computer sound synthesis, explained his work in designing spatial illusions and sound metamorphosis.

Figure 1: Excerpt of the notes written by Gérard Grisey during Ligeti's lessons in Darmstadt on July 24, 1972

(© Paul Sacher Foundation).

D'eau et de Pierre, then still in progress, was impacted by all these discoveries. As underlined by Cagney, Grisey here for the first time not only used "the modelling of ensemble harmonies on sum and difference tones" but also adopted "a style in which sound is always in flux."[14] In November 1972, Grisey achieved *D'eau et de Pierre* and began his residency at the Villa Medici in Roma where he composed *Dérives* (1973–74) for orchestra and amplified ensemble and *Périodes* (1974) for 7 instruments.[15] No longer restricted to the aesthetic production of natural resonances, spectral models now offer in these two pieces series of numbers which serve to control the temporal structure as well as many compositional processes.[16] In order to develop a new musical grammar anchored in scientific considerations, Grisey educated himself at this time in acoustics, acquiring scientific books, including Fritz Winckel's *Vues nouvelles sur le monde des sons* and Émile Leipp's *Acoustique et Musique* (1971).[17] Subsequently he never stopped purchasing such scientific books, which, to his eyes, should be part of the composer's *atelier* alongside musical scores and orchestration treatises.[18]

Genesis of the instrumental synthesis method

The harmonic spectral models Grisey established in *Dérives* and *Périodes* are deduced from acoustical reality. A sound generating a clear pitch sensation holds a harmonic or quasi-harmonic structure; that is, its spectral components are multiples of a fundamental frequency. The musical transcription of this physical property acts as an auditory tag in the listening experience due to the strong consonance sensation generated. Grisey elaborated his music on the basis of the attractive force of this kind of pole. But spectral models also function as number generators used for manipulating musical parameters and controlling rigorous compositional processes. Grisey always had a comprehensive and strict vision of the sound journey in each of his pieces; he did not like arbitrary choices and resorted to these numerical values in structuring his musical grammar. Structuralism inherited from serial music, and natural sound models inherent to spectral music, comfortably coexist in Grisey's mind. Structural organization is now, though, only derived from physical natural phenomena rather than from abstract mathematical operations, as Fabien Lévy remarks:

> Musical structuralism found the rationale for its epistemological validity in both science and music. In Grisey and Murail it comes from another, more applied science, one that is more physical and psychological than mathematical. In the 1950s and 1960s, science was giving a more formal organisation of structure and *a posteriori* clues as to the practical realisation of the work, that of the spectral musicians is more involved in checking/examining and understanding the perceptive reality and possibly inferring the structure in a more formal manner. In the 1970s there was further simplification from an induced perception of the structure to a structure deduced by perception.[19]

The method of instrumental synthesis—outlined in *Dérives*, then refined in *Périodes* to become one of the most emblematic spectral techniques—illustrates Grisey's attention to both natural models and formal procedures. This technique, described in one of Grisey's first texts,[20] seeks to transpose into the instrumental domain the electronic principle of additive synthesis, which consists of constructing complex sounds by adding individual frequencies. Musicians are substituted for frequency oscillators and they play notes corresponding to the spectral components of the sound being constructed. But instrumental sounds are not pure tones; each is itself by nature a microsynthesis. "To distinguish the latter," Grisey explains, "let us call macrosynthesis the instrumental synthesis that aims to elaborate the sound form."[21]

Dérives is based on a harmonic spectrum that is an aggregate consisting of twelve equal temperament pitches (E♭1, B♭2, G3, D♭4, A4, D5, A♭5, B5, C6, F6, E7, and F♯7) intended to approach the natural components of a harmonic spectrum with fundamental frequency E♭1. At this time, the composer, still a novice in acoustics, referred in his sketches to a harmonic "prism" rather than spectrum and made many approximations and sometimes mistakes concerning the correspondence between the musical notes and physical frequencies.[22] These pitches are consistent with the twelve notes of the chromatic scale,

which indicates that this prism reflects the will to consider spectral structure chromatically rather than transcribing a specific sound model. By arranging the twelve notes of the chromatic scale (approximately) into components of this spectrum, "Grisey reaches a sort of spectral atonalism".[23] Beyond this precarious design, the prism determines the overall structure of the piece, influences the development of several individual sequences, and acts as a junction between those sequences: shifts between the small amplified ensemble and the orchestra are tied to notes that make up the harmonic prism. According to the composer,[24] instrumental synthesis is approached in the last section of *Dérives* by composing a kind of spectral pedal in which instrument relays maintain the main prism's harmonics. Above this pedal tone, Grisey gradually sets up his six periodic events based on secondary prisms derived from the main prism. The construction of such a pedal tone based on a harmonic spectrum is very similar to Stockhausen's writing process in *Stimmung*. There is nothing revolutionary here, since Grisey only uses a pool of notes to approximate the frequencies of a harmonic spectrum. But when the composer decides, at the end of *Périodes*, to refine this technique by respecting both the spectral and temporal characteristics of the inner life of sound, the auditory result is quite different.

The spectral model used in *Périodes*, and its role in the structuring of the piece, are briefly described in the score preface, which could be viewed as Grisey's first theoretical text. Above a musical staff, Grisey indicates the frequencies equivalent to the first harmonics of a fundamental E1's spectrum. He then seeks to transcribe them as accurately as possible, using quarter tones and deviations of a sixth tone. Twelve frequencies within this harmonic spectrum are selected and shape his formal model: the first eleven odd harmonics (from the fundamental to the twenty-first), to which are joined the second harmonic. *Périodes*' original model, made up of this set of notes, is based upon a harmonic spectrum and not upon a specific instrumental sound. Once it is established, Grisey deduces from this model a pool of pitches and also two different series of numerical values: the harmonic ranking produces what we call the *series of partial harmonic numbers*; and the intervals between two notes within his model—expressed here in quarter tones—make up the *series of intervals between harmonic partials*. These series of pitches and numbers are at the heart of *Périodes*' compositional processes.[25] In the last section of the piece, Grisey develops his idea of instrumental synthesis considerably, asking the seven performers to replicate, one by one, the pitches of the original model transposed an octave higher. The fundamental is assigned to the trombone reinforced by the double bass, while the harmonics are played by other instruments. How do we perceive such a sound structure? Does the synthetic spectrum arising from this macrosynthesis represent, at a new level, the inner life of a trombone's sound?

Deconstruction of a myth

As well as using microintervals to approach more closely the physical characteristics of musical harmonic sounds, Grisey also seeks to reproduce the classical structure of instrumental sounds. Such sounds are generally contained within three periods:

1) Attack transient: the spectral components appear not concurrently but with very small delays and in an order dependant on the source.
2) Sustain period: components are relatively stable, each with its own intensity.
3) Decay transient: components gradually fade out, the order of their disappearance depending on the original source.

The reproduction of this temporal structure was undoubtedly influenced by spectrogram representations of sounds—and accompanying explanations—given in Winckel and Leipp's books. Grisey's imagination was stimulated by these visual sound forms. The musical ensemble, through the prism of the writing process, acts as a sound microscope, retracing the temporal evolution of spectral components. In order to erase the timbral identity of individual instruments, musicians are asked to enter imperceptibly. All of their sounds merge like magic, delivering an auditory ambiguity: do we hear a harmonic or a timbral structure?

The auditory image resulting from this macrosynthesis is neither a chord, nor a single orchestral timbre, but something liminal which seems breakable, at the border between fusion and segregation. The search for liminality is an essential aspect of Grisey's writing.[26] Grisey operates a temporal dilatation in order to aurally suggest what the spectrograms show visually: not stable structures but something with a lifetime and fluctuating energy. Concerning the end of *Périodes*, Grisey states: "The organization and formant of this spectrum come from the analysis, on the same pitch, of a trombone's spectrogram."[27] Cross-refererencing sketch studies, score analysis, acoustical considerations, and interviews with Grisey's close collaborators, we have reconsidered this assertion and demonstrated that the composer did not really use the analysis of a trombone sound sample at this time, either for establishing *Périodes*' model or for conducting this macrosynthesis at the end of the piece.[28] In both *Dérives* and *Périodes*, spectral models do not yet come from the transcription of any particular instrumental sound's spectrograms. Nevertheless, the gradual construction of this synthetic spectrum produces a powerful and atypical auditory image. Conscious of the singularity of this hybrid structure, the composer decided to develop it through *Partiels* (1975) for eighteen musicians.

This is how the cycle *Les Espaces acoustiques* was born. As retrospectively explained by the composer in 1993: "*Les Espaces acoustiques* seems to me today like a huge laboratory where spectral techniques are applied to various situations (from solo to large orchestra). Some pieces have a demonstrative, almost didactic aspect, as if, excited by the discovery, I had worked hard to convey as best I could the characteristics of the language I was progressively inventing."[29] With *Vagues, chemins, le souffle* and *D'eau et de pierre*, both completed in 1972, Grisey profiled the foundations of his musical grammar. During his two-year residency at the Villa Medici, between 1972 and 1974, he genuinely laid

these foundations, using the harmonic spectrum as a formal model leading the compositional processes and as a natural model that serves as an auditory tag in the listening experience. Scientific books helped him to develop his original epistemological approach to musical composition. In the fall of 1974, Grisey returned to Paris; wishing to increase his knowledge of acoustics, he decided to follow Émile Leipp's lessons at the *Laboratoire d'Acoustique Musicale*, and a few years later he started to collaborate with Michèle Castellengo, carrying out spectral analysis of instrumental sounds. The work of these acousticians impacted some of the new musical processes Grisey innovated in the other pieces of *Les Espaces acoustiques*.

The first spectral analyses conducted by Grisey at the *Laboratoire d'Acoustique Musicale*

From Émile Leipp's lessons…

Grisey's annotations (including dates, comments, and highlighting) on his scientific textbooks constitute relevant information for understanding how he elaborated numerous spectral techniques by himself during his residency at the Villa Medici. Leipp's and Winckel's books had a definitive, crucial impact on the development of many compositional techniques. Appealed to by both academics (acousticians, psycho-acousticians, music psychologists, musicologists) and musicians (composers, performers, music teachers), these books address acoustics in a broad sense: the science of sounds as they are perceived and integrated by the human listener. First published in 1971 and thereafter published in many subsequent editions, Leipp's *Acoustique et musique* received acclaim for the author's original and pedagogical approach to acoustics. Leipp had been a primary school teacher who dreamt of crafting the perfect violin. This aspiration led him to develop after the Second World War an interest in acoustics. With the support of his mentor Abraham Moles, who brought the first sonagraph to France in the mid 1950's, Leipp began using this revolutionary and sophisticated device to investigate the world of sounds. After defending two theses in 1960, he was accepted into the CNRS (the French National Centre for Scientific Research) and in 1963 created the first laboratory in France dedicated to the study of music and musical sounds through the prism of acoustics.[30]

It is important to remind ourselves that in the 1960s and 1970s few research centres were equipped with a sonagraph (Figure 2). This device produces a visual representation of the frequency spectrum of sounds as a function of time. Such images show how the energy spreads and evolves inside the sound. Although it has an analogy with traditional musical notation, musicians were not yet familiar with this kind of sound representation, which was more restricted to scientific contexts. Leipp, though, was teaching acoustics essentials to trainee music teachers at the Paris Conservatoire, and his class was also open to composers and instrumentalists wishing to discover the physical structure of sounds and the mechanisms of auditory perception. Grisey was one of these students. According to a certificate found at the Paul Sacher Foundation, he followed Leipp's lessons

between October 26, 1974 and May 25, 1975. This education helped Grisey to anchor his proficiency in acoustics and to explore this knowledge in a musical context. For example, the entire first section of *Partiels* consists of gradually transforming the synthetic harmonic spectrum displayed at the end of *Périodes* into an inharmonic and noisy spectrum. The spectral and temporal structure of each synthetic spectrum as well as the degree of change between successive occurrences are controlled in every detail.[31] Grisey seems inspired by principles from information theory thanks to Abraham Moles' book on the subject, which he presumably acquired at this time.[32] Moreover, he translates into practice what he learned in acoustics thanks to Leipp's book and lessons: the use of Savart units for the temporal structuring, and the elaboration of writing processes exploring formants, inharmonic overtones, and sum and difference tones. Leipp's lessons were theoretical as well as practical and consequently occurred at the *Laboratoire d'Acoustique Musicale*. We assume that is how Grisey attended a spectral analysis for the first time and met Castellengo, who was completing her PhD thesis at the time.

Figure 2: The Kay Elemetrics Spectrum Analyser 7029A was the sonagraph model in use at the Laboratoire d'Acoustique Musicale in the 1960s and 1970s.

… to collaboration with Michèle Castellengo

Michèle Castellengo built her career in the footsteps of her mentor Émile Leipp, using the sonagraph to study musical sounds and to investigate mechanisms of musical listening. She succeeded Leipp at the head of the laboratory in 1982 and published a book in 2015 retracing forty years of her research in musical acoustics.[33] In the spirit of Leipp's *Acoustique et musique*, Castellengo's book is aimed at a wide audience and demonstrates great pedagogy thanks to the presence of "420 sound examples and their decrypted spectrograms".[34] Grisey and Castellengo started collaborating in 1977 while the composer was working on *Modulations*. Together they carried out spectral analysis of many instrumental sounds and, for the first time, Grisey literally transcribed some of these spectrograms for compositional purposes. Before focusing on their collaboration and Grisey's first spec-

tral transcriptions, let us look at some obscure aspects concerning the spectrogram collection of the composer.

Two important folders containing more than one hundred spectrograms (original as well as copies) are held at the Paul Sacher Foundation. Five original spectrograms are included in a file entitled "sourdines de cuivres" (brass mutes). Two of them show a chromatic scale (ascending and descending) played on a clarinet and three of them show a chromatic scale played on a trombone with and without mutes. The date 29-11-73, only mentioned on one clarinet spectrogram, casts doubt on the chronology of events. Was Grisey in possession of all these documents at the end of 1973 during his residence at the Villa Medici? Had he already carried out spectral analysis at this time? Is it possible that *Périodes* could be based on one of these trombone spectrograms as the composer retrospectively claimed in some of his writing?[35] First of all, it is difficult to say if the date is written by Grisey himself or someone else. Second, during the interview conducted with Castellengo, we asked her if she could have carried out these trombone sound analyses before 1974.[36] She remained sceptical and decided to examine her own archives, which still contain the original recording sessions from which her spectral analyses were done. Castellengo's new analysis has shown that the trombone spectrograms in question correspond to recordings made in 1978.[37] In conclusion, at the time Grisey was composing *Périodes*, he was obviously familiar with spectrogram representations thanks to acoustics books; perhaps he was even in possession of a few original spectrograms like the clarinet one. But there is every reason to believe that he began to collect them only when he started frequenting the *Laboratoire d'Acoustique Musicale* at the end of 1974.

It is only toward 1977 that Grisey and Castellengo began to collaborate closely, organising recording sessions with musicians to examine the spectral characteristics of playing techniques or mutes on different instruments. "Grisey became part of a collaborative project. He made significant efforts to take time and spend time with musicians whom he brought along for the project. He invested time and energy and helped with the analyses both to understand what was being done and to draw conclusions for himself."[38] This collaboration informed the writing not only of *Modulations* and *Transitoires* from *Les Espaces acoustiques* but also *Tempus ex machina* (1979) for six percussionists, *Solo pour deux* (1981–82) for clarinet and trombone, and many other pieces.

On March 25, 1977, Grisey came to the laboratory with the trumpet player Louis Roquin and the horn player Gilles Mahaud. During this session, many sound samples (chromatic scales or individual notes) were recorded and made the subject of spectral analyses. Some spectrograms served as models in the fourth section of *Modulations* and the third section of *Transitoires*. In the latter piece, Grisey also resorted to spectral analysis of double bass sounds from another recording session that occurred on April 16, 1980 with the double bassist Joëlle Léandre. During each work session, Grisey had a systematic approach, focusing on a specific note (most of the time an E, which is at the heart of *Les Espaces acoustiques*) which musicians had to play in as many ways as possible. Attention was paid to the sound itself as well as to its visual representation, once analyses had been completed by Castellengo. A letter sent to Castellengo in 1980 reveals the composer's ex-

citement while discovering the new spectral analyses done on double bass sounds (Figure 3).

Figure 3: An original letter sent by Gérard Grisey to Michèle Castellengo probably in June 1980 after Grisey had just settled in Berlin and begun work on *Transitoires* (1980–81)

(© Castellengo's private archives). This letter was added in the expanded edition of Grisey's writings published in 2018.

"Thank you so much for the sonograms!

I threw myself into them immediately and they are spread out on a big table…

I have written three levels of extrapolation but the sound is so rich that I will need the entire orchestra. The quantity of noise is considerable and the sound *on* the bridge (ASP) is really as astonishing to see as to hear. How could we make this work with 50 musicians?

Since our letters crossed in the mail I remind you that I am awaiting on tenterhooks (!) *the different kinds of pizz* forte as well as a progressive passage from the bridge (ASP) in the ord. position and vice versa. The one which you called the E of "Partiels" is not very convincing and more importantly *too short*.

I will remind you of the measures used, both of which are useful.

4,8″2000 Hz (scale 500)

4,8″4000 Hz

Thanks in advance

We'll speak of all this again if I get to Paris in June

Kind regards

Gérard"

The interdisciplinary collaboration between Grisey and Castellengo provided a wealth of information for both of them. On the one hand, Grisey developed new compositional strategies, simulating and interpreting acoustic phenomena facilitated by the spectral analyses. On the other hand, Castellengo acquainted herself with unusual instrumental playing techniques and saw her scientific analyses integrated into artistic projects. The acoustician underlined the collaborative nature of their work.

> He listened to what I was saying and was paying attention; it was a meeting of the minds. I asked him questions. There was a true exchange of ideas insofar as he was really trying to understand and to integrate the ideas. He had this approach towards integrating knowledge. And I was delighted; I had always dreamt of that. Afterwards, when he was a professor of music analysis at the Conservatoire, he brought me his students and his class twice so that they could discover the recordings, the analyses. We had remarkable sessions with him.[39]

Spectral analysis of trumpet sounds played with wah-wah mute

The sonagraph Castellengo used with Grisey for carrying out spectral analysis was a Kay Elemetrics Spectrum Analyser bought by the laboratory at the beginning of the 1960s: a magnetic tape with recorded sounds is mounted on a rotating disc; an electrically sensitive paper is placed on a metallic cylinder which is connected to this disc; and a stylus linked to a bank filter sends a spark and marks the paper each time a spectral component of the recording signal coincides with one of the filters.[40] The spectrogram attempts to perform an analysis similar to that of the ear, and it presents the results in an orderly manner to the eye. Spectral components are spread out in the vertical axis, with high frequencies on the top and low frequencies on the bottom. The more intense the frequency, the more powerful the spark; intensity is consequently expressed by darkness. At this time, the sonagraph was able to cover the frequency range between 85 Hz and 8000 Hz and the filter's bandwidth could be set on 45 Hz or 300 Hz. At normal speed, it was possible to analyse only 2.4 seconds of sound. If the speed was multiplied by x times desired, the frequency system was consequently divided by the same factor x.

During their working sessions, Grisey and Castellengo first recorded sound excerpts, asking musicians to produce scales or single notes with different playing techniques. Analyses were done later in the presence or absence of the composer. Castellengo remembers that trumpet and horn analyses were carried out in the continuation of the recording session that occurred on March 25, 1977. While she was tuning the sonagraph for a new analysis, Grisey himself studied and annotated the completed spectrograms. During this working session, they studied the effects of mutes on trumpet and horn sounds. Mutes change both the timbre and the sound level of the instrumental source: "Brass mutes," explains Grisey, "act like a double filter on an equalizer: some harmonic areas are suppressed and new formants appear."[41] Formants originally describe spectral peaks in the voice spectrum. More broadly, they define intense and stable spectral zones of any sound

independent of the pitches being played. This acoustical characteristic is a core compositional element in Grisey's music.

One of the spectrograms from this working session is entitled "TROMPETTE – Sourdine WaWa – [tube retiré]" (Wah-wah mute with the stem withdrawn, Figure 4). The main structure of the wah-wah mute (also called a Harmon mute, after the manufacturer) is a solid ring of cork that completely blocks all of the air leaving the bell. In a hole on the front of the mute there is a cup on a tube, called a stem, that can be slid in or out or removed completely, depending on the sound required. The possibilities of timbre and level transformations are numerous as a function of the insertion of the stem into the main structure. The spectrogram shows thirteen notes played staccato, as tiny breaks between each note suggest. There are few indications concerning time and frequency scales, but we know that the second and seventh notes are respectively "SOL_2" (G3 = 196 Hz) and "DO_3" (C4 = 262 Hz). It is consequently a chromatic scale from F♯3 to F♯4 inclusive. We can deduce, thanks to these pitch indications, that the spectrograph was traditionally tuned: that is to say, frequency range = 85–8000 Hz and duration = 2.4 seconds. As we can see, some gaps appear in the spectral structure as well as in enriched areas, independently of the notes which are being played. The mute acts as an equalizer by constantly amplifying or reducing some specific frequency areas: components under 1000 Hz are intense; gaps appear between 1000 and 1500 Hz, 2000 and 2200 Hz, and 3900 and 4200 Hz; the two main formants are located around 1700 Hz and between 4500 and 5400 Hz, approximately.

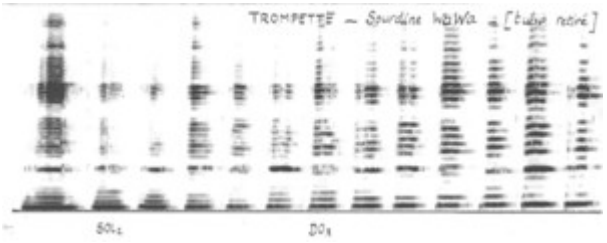

Figure 4. A spectrogram carried out by Castellengo following the recording session organized on March 25, 1977 with Louis Roquin (trumpet) and Gilles Mahaud (horn). This spectrogram represents thirteen notes of a chromatic scale (F♯3—F♯4) played on a trumpet with the wah-wah mute (stem withdrawn)

(© Castellengo's private archives).

The original recording of the working session was realized on a 7-inch reel of quarter-inch-wide audio tape of the type in use from the 1950s to the 1970s; it was digitized in 2012. This 28′21″ recording includes many cut-offs but still appears as a relevant document for grasping the fruitful collaboration between Grisey and Castellengo and examining their interactions with musicians. New spectral analysis can also be carried out from the recording to help identify the sounds or scales behind each spectrogram. For example, the thirteen notes visible on previous spectrograms in reality come from a thirty-one note chromatic scale (Figure 5). Through this method it is possible to match the sound ex-

cerpts with their visualization representations. But the main difficulty is to identify the spectrograms Grisey explored in his compositional processes. The composer has reproduced in all his writings only one spectrogram representing an E pitch played *sul tasto* by Joëlle Léandre.[42] By way of explanation, he briefly describes the shift of the temporal scale, using as an example the section of *Transitoires* where the instruments of the orchestra supersede the spectral components of the model (score cues 17–43). The instrumental synthesis technique is considerably refined here, since the orchestra literally suggests by simulation the original sound model. A true dialectic between microphonic and macrophonic worlds is established here: the double bass plays a rhythmic pattern on the single note E1, using varied playing techniques (normal, *sul tasto*, *pizzicato*…) and the orchestra answers this pattern by simulating the corresponding spectrum. The orchestration is also itself guided by the spectral analysis, as the composer explains: "One notably finds a correspondence between, on the one hand, the volume and spectral richness of the orchestral instruments and, on the other hand, the depth and intensity of the spectral formants that were the basis for the model."[43] By virtue of spectrogram transcriptions, Grisey can faithfully reproduce the inner life of his sound models. But his first transcriptions, carried out for *Modulations*, have a different goal, serving to filter a spectral polyphony.

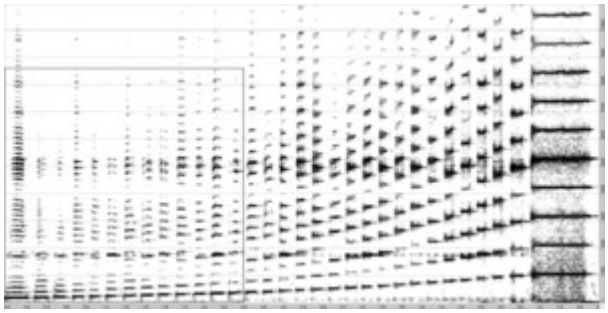

Figure 5. New spectral analysis (6 s, 0 – 11000 Hz) of the chromatic scale played on a trumpet with with the wah-wah mute (stem withdrawn) ~~the Harmon mute~~. This analysis was carried out with the software Audiosculpt (Hanning window, FFT with 1500 samples) from the original tape recording which was digitalized. The spectrogram presented in Figure 4 corresponds here to the framed portion.

A case study: transcription of instrumental sound models in the fourth part of *Modulations*

Temporal structure and musical journey

Modulations[44] is divided into five parts. The duration of each part is determined according to the series of intervals between harmonic partials of the original spectrum Grisey set up in *Périodes*. As in *Partiels*, the unit of measurement Grisey used for expressing

these intervals is the Savart. To calculate the interval between frequencies m and n in Savart, the formula is: 1000 log (m/n). The values thus obtained are then multiplied by the common factor three-fourths, applied by the composer specifically in *Modulations*. The fourth part of *Modulations* comprises three sections whose theoretical durations are respectively 110, 82, and 65 seconds. These values are deduced from the *series of intervals between harmonic partials* previously mentioned: Grisey resorted here to the intervals between the fifth and seventh, seventh and ninth, and ninth and eleventh partials of his original spectrum.[45] Each of the three sections is divided successively into subsections whose durations follow in turn logarithmic curves that are totally predefined. In the first section (110″, cues 31–36), there are thirty subsections which become shorter and shorter: a complex polyphony is gradually built and the density of notes becomes higher and higher. In the second section (82″, cues 37–40), there are twenty subsections which become longer and longer: the polyphony is gradually transformed in "vague aggregates" which become more "precise." In the third section (65″, cues 41–44), there are just five subsections which are even lengthier: the polyphony slowly totally disappears to be replaced by a "perfect homophony."[46]

During this fourth part the ensemble is split into four similar groups, each of which constructs a five-voice polyphony. The main low voices played on brass instruments follow a melodic gestalt similar to the neumes previously composed in *Prologue* (1976) for solo viola. Pitches derive from a spectrum with an E0 fundamental. The four other voices within each group are deduced from other spectral models. Three of them are established thanks to spectral transcriptions of brass sounds with mutes and one of them simulates an imaginary mute. Musical transcriptions of these spectral models are reproduced in Grisey and Baillet's analyses, but there are no visual representations of the spectrograms from which they are derived.

> At the beginning of these few minutes: four spectra coming from the spectrographic images of brass instruments playing the same note with different kind of mutes. Formant and filtering generated by the mutes produce stylized spectra limited to a few harmonics: A, B, C, D. These spectra are then distorted and shifted in inharmonic spectra: A′, B′, C′, D′, then A″, B″, C″, D″.[47]

Grisey just gives snippets of explanation concerning the spectral transcriptions and the data exploration. The compositional process is actually extremely complex and all parameters are precisely controlled thanks to various operational modes. As a result of sketch studies, Baillet details more precisely the complex processes in action, but he does not explain how the transcriptions were done and does not discuss auditory implications.[48] Having reminded ourselves of the compositional processes involved in the construction of the polyphony, we wonder how Grisey carried out his transcriptions and try to identify the spectrograms behind them.

The following original sketch (Figure 6) deals with the harmonic/melodic structure of the beginning of *Modulations*' fourth part. Temporal and rhythmic structuring follow other processes indicated on separate graph papers. Some spectral models are precisely notat-

ed on the special insert on the bottom left hand side of this document (staves 21–37).[49] The rest concern pitch organization in the fifteen first subsections, which are delimited by bars and numbered at the bottom edge of the document (staff 40). At the top (staves 1–3), Grisey indicates the global harmonic evolution of the entire part which is allocated to the main voices within the four instrumental groups which will be modified through the entire section.

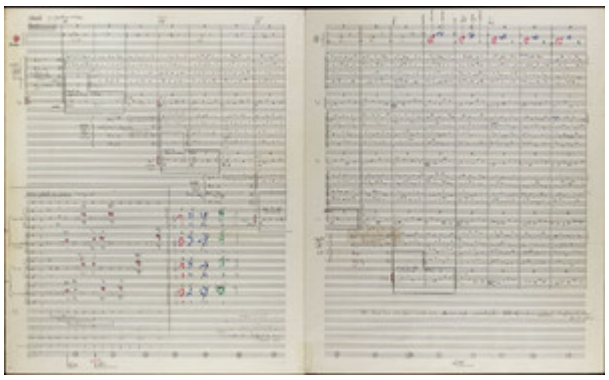

Figure 6. One of Grisey's sketches focused on the spectral transcriptions (bottom left) and the construction of the spectral polyphony at the beginning of *Modulations'* fourth part. This document (31 centimetres high and 50 centimetres long) represents the first sheet—of four—established by Grisey to determine pitches for the entire fourth part.

(© Paul Sacher Foundation).

Pitch structuring within the main voices

Grisey arranges the four instrumental groups to have a homogenous timbre: two string instruments, percussion/keyboards/harp, a woodwind instrument, and a brass instrument. Each of the four instrumental groups is led by the brass instrument. The number of notes, permutations, and degrees of change within the neumes these instruments play are derived from *Prologue*.[50] The pitches—notated in staves 1–3 and affiliated to the neumes—are drawn from the E0 (20.6 Hz) harmonic spectrum. Grisey indicates in each box different groups of notes: three at the beginning (exceptionally two in the second subsection) and then four from the twelfth subsection. The first interval, written just after each barline, restores the pitch range of notes chosen by the composer within the harmonic spectrum. In the second and third groups respectively the indicated notes correspond to odd and even harmonics. In the fourth group the notes correspond to harmonics shifted several octaves below. From the eleventh subsection, Grisey starts using a red pen for odd harmonics, a blue pen for even harmonics, and a green pen for octave shifted harmonics. Numbers on the first staff refer to the number of different pitches in each subsection.

During the entire first section of the fourth part of *Modulations*, Grisey aims to increase the density of notes and the inharmonicity while the pitch range becomes lower and lower. This global process is led by the main voices. For example, in the first subsection the

three pitches correspond to harmonics 21, 23, and 24 of the E0 harmonic spectrum. They are included between A4 and B4. In the thirtieth subsection (not visible on this sketch), there are thirteen different pitches included between B1 and D♭3: only three of them come from the harmonic model (harmonics 3, 4, and 5) while all others correspond to shifted harmonics. At this precise moment Grisey reaches a climax of inharmonicity and density. Shifting harmonics down by octaves is a recurring process Grisey uses when transforming a harmonic model into an inharmonic one. In the second section, the process is reversed: aggregates become gradually less compact—the pitch range increases—and become more and more harmonic. The last section of *Modulations*' fourth part is designed to come back to stability and concludes with a series of complex chords deduced from the sum of the inharmonic spectra A″+B″+C″+D″.

Pitches that emerge from this global harmonic transformation are approximated at the half tone and given, as we previously mentioned, to the main voices played by brass instruments. The score is rearranged to highlight these groups, which are not immutable: instruments within a group can disappear to the benefit of one another. For example, in the first group, the main voice is played by trumpet 2 (cue 31), then by trumpet 1 (cue 32), then trombone 2 (just before cue 36) re-joined by trumpet 1 (just after cue 39); the two instruments work in tandem to play the main voice and systematically use the same mute until cue 42. At this moment, since the polyphony has almost coagulated to become a series of homophonic blocks, instrumental parts are once again arranged traditionally in the score.

Pitch structuring in the other voices

In each group, the pitches of secondary voices are dependent on both the main voice and on the harmonic models deduced from spectral analysis of the instrumental sounds. The sketch in (Figure 6) shows that group A ("spectre Harmon") is affiliated to a trumpet sound with a Harmon mute; group B ("spectre cor +") to a stopped horn sound; group C ("spectre sourd. Imag") to a sound produced by a horn with an imaginary mute; and group D ("spectre BOL") to a trumpet sound with cup mute. The four spectral models are clearly indicated on the bottom left side of the sketch, in the inset entitled "Analyse spectrale des sourdines" (spectral analysis of mutes, Figure 7).

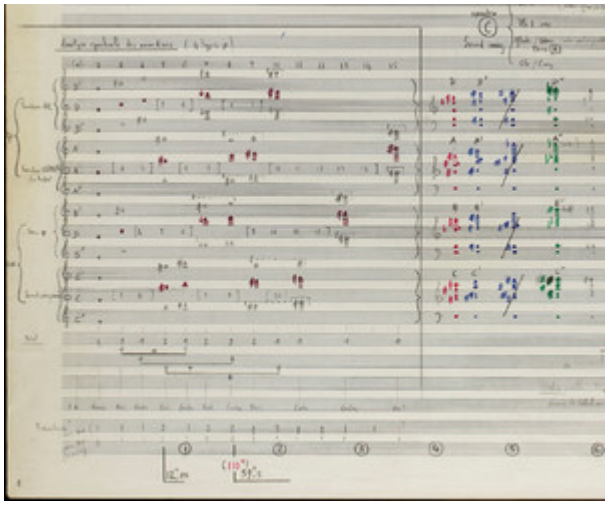

Figure 7. Detail of the transcriptions of instrumental sound models derived from spectral analyses done in collaboration with Castellengo.

The "Harmon" denomination often refers to the use of wah-wah mute without the stem; that is why Grisey sometimes employs "Harmon" and at other times "wah-wah mute without stem". The cup mute results from the cross between the straight mute and the plunger, forming a cup over the bell. Lastly, the denomination "+ horn" means stopped horn: this technique consists in stopping the horn by putting the hand inside the bell. To obtain the stopped sound, the player has to fully close off the bell of the instrument with either the right hand or a special stopping mute. The common fundamental (harmonic 1) for all Grisey's models is E3. Each model includes five notes corresponding to components lower than the 15th harmonic: harmonic 2 and the four other harmonics indicated in red in the original models (A, B, C, D). Other models (A′, B′, C′, D′ and A″, B″, C″, D″) are inharmonic models derived through pitch shifting. Below these twelve staves, Grisey indicates the number of times each harmonic appears. Only harmonic 2 (E4) appears in each transcription; the fundamental and harmonics 12 and 14 never appear. All these data are compiled in the following table (Table 1). Each model is thereafter transcribed one octave lower and written beside the inset as chords with different colours (original harmonic model in red and inharmonic models in blue and green).

Table 1 Pitches selected from the four spectral models

Harmonics ranking		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Musical transcription		**E3**	**E4**	**B4**	**E5**	**G♯5**	**B5**	**D6↓**	**E6**	**F♯6**	**G♯6**	**A6azk**	**B6**	**C7k**	**D7↓**	**D♯7**
Trumpet	Cup mute (Group D)		X	X	X			X			X					
	Harmon mute (Group A)		X			X			X	X						X

Horn	Hand in bell (Group B)		X	X				X	X					X		
	Imag-inary mute (Group C)		X			X	X			X		X				
Pitch occurrence		0	4	2	1	2	1	2	2	2	1	1	0	1	0	1

The leading brass instrument within each group plays the bass of the five-voice polyphony. This bass consists of *Prologue*'s neumes transposed to pitches derived from the E0 harmonic spectrum. Pitches of other voices are selected as a consequence of the spectral chords transposed to this bass. The spectral models consequently act like a comb filter whose position is governed by the main voice. Let us focus on the first subsection of this polyphony in construction. The main voice of Group A is led by trumpet 1 which plays the neume (B♭4 – A4–B4). These pitches are systematically associated with the second harmonic of the Harmon mute spectral model. Pitches of violin 2 and violin 1 are respectively calculated so as to coincide with the ninth and fifteenth harmonics (encircled numbers) of this model; that is, B6, D♭7, and C7 on the one hand and G♯7, B♭7, and A7 on the other hand. Violin 2 plays a seven-note pattern while violin 1 plays a six-note pattern. Two new voices appear in the next subsection; they consist of a four- and five-note pattern whose pitches respectively correspond to harmonics 5 and 8 of the spectral model. The process is started again for the three other groups, which respectively enter on subsections 4, 7, and 10. Grisey gradually builds a 20-voice polyphony.

Gradual transformation of musical structures

During the entire first section (cues 31–37), Grisey links each instrumental group to his corresponding model: spectrum A (trumpet Harmon mute) for the first group, spectrum B (horn stopped sound) for the second group, spectrum C (horn with imaginary mute) for the third group, and spectrum D (trumpet with cup mute) for the fourth group. The transposition process is "neither parallel, nor synchronous," explains Baillet:[51] this means that notes within voices can be reordered or repeated and that the five voices are not synchronous at all. In the second section (cues 37–41), the spectral chord association is inverted so that the four groups are respectively associated with spectra D, C, B, and A, which will soon be transformed into spectra D′, C′, B′ and A′. The goal of this first interpolation is to gain a little removal from the harmonic model. The transposition process is now "parallel and asynchronous": the melodic lines within each group are parallel. A last interpolation is enacted, and spectra D″, C″, B″, and A″ are complete at the beginning of the last section (cue 41). The transposition process is parallel and synchronous, so that each group plays a series of chords producing an inharmonic chord melody.

> Passing through spectra A′, B′, C′, D′ (second section) doesn't produce a relevant change, although these chords are, in absolute terms, far removed (if they could be heard) from A, B, C, and D, since they are not harmonic. On the other hand, instrumental synchronisation inside each group on spectra A″, B″, C″ and D″ lets them be heard clearly as sound colour. But the musical structure is complex because of the transposition's diversity, even if the pitches played by brass are at this time harmonic.[52]

Now that the compositional processes are partially deciphered, let us focus on the instrumental sounds which would have been transcribed to establish the spectral models. Does the composer base the model on E3 pitches played on trumpet and horn with different mutes? Or does he only try to explore the spectral characteristics of these mutes without

focusing on a specific pitch? Whatever the strategies, we will discuss the impact of these instrumental models on the listening experience, wondering if the sound result could approach the colour of the brass muted instruments being simulated.

Identification of the instrumental sounds behind the models

Assuming that the spectral models stem directly from spectrographic analyses (except of course spectrum C which is corresponding to an imaginary mute), we tried to identify the matching spectrograms in Grisey's archives. Altogether there are more than thirty spectrograms of trumpet and horn sounds. Most of them represent chromatic scales such as those in Figure 4. According to us, Grisey used that specific one for elaborating the Harmon mute model in *Modulations*. But which sound does he choose exactly? Grisey's models (Figure 6) suggest he systematically transcribed a spectrum with an E3 as fundamental. But there is no such pitch on the trumpet spectrograms, since the musician plays a trumpet in C. The tessitura of this instrument is F♯3–C6. Grisey could consequently not transcribe this specific pitch for the establishment of his model and probably resorted to a transposition. Pitches of his model correspond to the harmonic [2, 5, 8, 9, 15] while the harmonics [3, 4], [6, 7] and [10, 11, 12, 13, 14] are excluded. As previously mentioned, mutes act as a filter, reinforcing and weakening frequency zones (Figure 4). Depending on the pitch played, some groups of harmonics can consequently be more intense or more weak. The first sounds of the spectrogram (from F♯3 to D4) cannot serve as models since the harmonic 5 is systematically almost non-existent. Only the four last sounds (from D♯4 to F♯4) have a spectral structure which matches Grisey's model. Since the pitch E is the pedestal of the cycle *Les Espaces acoustiques*, the composer may just have decided to select this pitch within the chromatic scale; that is, E4. Our hypothesis is that Grisey is in this case more interested in constructing a model that is inspired by the spectral characteristics induced by the mute than in faithfully transcribing a specific single sound.

His use of E3 as fundamental instead of E4 is probably motivated by two considerations. First, the components within each model are positioned in the medium tessitura and can consequently easily be played by most of the instruments in the ensemble. Second, the E3 spectral harmonic model is at the heart of the instrumental synthesis technique explored at the end of *Périodes* and the beginning of *Partiels*. In the fourth part of *Modulations*, spectral models are based on the same pitch but they are explored in a completely different way. The four models appear as filters for selecting pitches within secondary voices of his polyphony. They are always transposed and consequently do not simulate the characteristics of muted sound. Formants correspond to static enriched frequencies; these areas inside the spectrum are independent of the pitch being played. If Grisey drew his inspiration from the formants of different mutes in establishing his models, he does not try to respect their characteristics. He favours complex harmonic evolution by transposing harmonics and does not seek to restore the formants by always emphasising the same pool of pitches for articulating secondary voices. *Modulations*' fourth section is built from instrumental sound models, but the compositional process does not generate at all stable en-

riched or weak frequency areas. Once completed, spectral models become out of step with their anchored reality and serve as pitch generators.

Conclusion

Grisey laid the foundation of his musical language at the beginning of the 1970s. His residence at the Villa Medici between 1972 and 1974 constitutes a turning point: during this time he taught himself about musical acoustics and information theory by studying scientific books written by researchers such as Leipp, Winckel, and Moles, to mention the most important authors. This new knowledge helped him to develop new original compositional approaches serving his creative vision. "From Moles' information theory," Orcalli reminds us, "Grisey retains the idea of music as time modulation as well as information contained in sound material considered a function of time."[53] From acoustics treatises, Grisey gained an awareness of composing the sounds themselves and discovered new ways of elaborating and controlling his musical material. Independently of their nature and origins, spectral models appeared as a pedestal for the establishment of a new vocabulary as well as the structuring of his grammar.

At first, Grisey resorted to theoretical harmonic spectra in building his models, as in *Périodes* for example. The instrumental synthesis technique used at the end of the piece imitates the inner life of sound, as revealed by the spectrograms which appear in this case as a metaphor for composition. Thereafter Grisey never stopped enlarging his scientific knowledge, with the goal of exploring in his work the diversity of sound phenomena. From 1977 he started conducting spectral analyses of instrumental sounds in collaboration with Castellengo in order, on the one hand, to conceive new spectral models and, on the other, to explore the best potential of each instrument through musical writing. "Are we moving," Grisey wonders, "towards the creation of a new orchestration treatise that would classify timbres and registers as a function of their spectral value, formants, and transients and no longer as a function of their instruments?"[54]

Grisey made authenticable spectrogram transcriptions for the first time in *Modulations*. Observation and analysis of spectral characteristics of brass mutes stimulated his creative process, helping him to develop new strategies, as evidenced by the construction of the spectral polyphony in the fourth part of that piece. If his music is definitively anchored in the acoustic reality of sound phenomena, the composer did not systematically seek to have a naturalistic approach, consisting of simulating these phenomena; they also were a springboard for organizing his musical thought. Analysing Grisey's music cannot be achieved without difficulty, since "he considered himself as the sole keeper of the key to his work and had no value for exegetes", as Dufourt underlines.[55] Sketch studies reveal the high degree of structuring in each of his pieces and help in analysing the score, but the auditory consequences also have to be addressed.

If Grisey drew his inspiration from sound phenomena and the characteristics of auditory perception, he did not neglect structuralism. Some of his compositional processes are not so distant from those in use in serialism. For example, spectra remain a core element of

his language: they not only generate the vocabulary, but also expand into the very structure of the work. The main difference with a serial approach is that Grisey's processes do not come within a combinatory logic but have a functional purpose. They serve to construct and articulate the musical journey he has predefined. Grisey always had a global vision of each of his pieces before composing any notes. Since his processes are derived from acoustic and psychoacoustic considerations and are often clearly perceived by listeners, the three analytical levels (poesis, neutral, and esthesic) tend to merge, according to Lévy.[56] In that sense, it seems crucial to approach Grisey's work in terms of musicological and acoustic analysis.

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Notes:

(1) Hugues Dufourt, *La musique spectrale: une révolution épistémologique* (Delatour France, 2014), 12.

(2) *Les Espaces acoustiques* is made up of six instrumental pieces: *Prologue* (1976) for solo viola, *Périodes* (1974) for 7 musicians, *Partiels* (1975) for 18 musicians, *Modulations* (1976–77) for 33 musicians, *Transitoires* (1980-81) for orchestra, and *Epilogue* (1985) for 4 horns and orchestra

(3) Jean-Jacques Nattiez, *Music and Discourse: Toward a Semiology of Music*, Trans. Carolyn Abbate (Princeton: Princeton University Press, 1990).

(4) Gérard Grisey, *Écrits ou l'invention de la musique spectrale*, ed. Guy Lelong with the collaboration of Anne-Marie Réby (Paris: Éditions MF, 2008).

(5) Jérôme Baillet, *Gérard Grisey: fondements d'une écriture* (Paris: L'Itinéraire/ L'Harmattan, 2000).

(6) Robert Hasegawa, "Gérard Grisey and the 'Nature' of Harmony," *Music Analysis* 28/2–3 (July–October 2009): 349.

(7) A. Orcalli, "La pensée spectrale," in *Théories de la composition musicale au XXe siècle*, vol. 2, ed. Nicolas Donin and Laurent Feneyrou (Lyon: Symétrie, 2013), 1511–74.

(8) Jean-Claude Risset, "The Computer can Merge Composition, Synthesis and Performance" [1994], in *Composer le son: Repères d'une exploration du monde sonore numérique* (Paris: Hermann, 2014), 47.

(9) For further details on Marie's teachings see François-Xavier Féron, "Sur les traces de la musique spectrale: Analyse génétique des modèles compositionnels dans *Périodes* (1974) de Gérard Grisey," *Revue de Musicologie* 96/2 (2010): 411–43 and Liam Cagney, "*Vers une écriture liminale*: Serialism, Spectralism and Écriture in the Transitional Music of Gérard Grisey," in *The Routledge Research Companion to Modernism in Music*, ed. Björn Heile and Charles Wilson (New York/Oxon: Routledge, 2019), 400–426.

(10) Baillet, *Gérard Grisey*.

(11) Liam Cagney, "On *Vagues, Chemins, le Souffle* (1970–72) and the Early Use of Resonance Chords in Grisey's Oeuvre,' *Mitteilungen der Paul Sacher Stiftung* 28 (2015): 49–54.

(12) François-Xavier Féron, "The Emergence of Spectra in Gérard Grisey's Compositional Process: From *Dérives* (1973–74) to *Les Espaces acoustiques* (1974–85)," *Contemporary Music Review* 30/5 (October 2011): 343–75.

(13) Gérard Grisey's Collection, Paul Sacher Foundation.

(14) Cagney, "Vers une écriture liminale," 415.

(15) *Dérives* requires an orchestra of fifty parts in addition to an amplified ensemble of thirteen instrumentalists. Completed in September 1974, it was premiered in Paris on October 31 by the Orchestre National de France, conducted by Reinhard Peters. During the winter of 1974, Grisey interrupted his work on *Dérives*, which was close to completion, to dedicate his time to *Périodes* for seven instruments, which the ensemble L'Itinéraire premiered on June 11, 1974 at the Villa Medici.

(16) Féron, "The Emergence of Spectra."

(17) Grisey's private library is held at the Paul Sacher Foundation. Some of his books, like Émile Leipp, *Acoustique et musique* (Paris: Masson, 1971) and Fritz Winckel, *Vues nouvelles sur le monde des sons*, trans. by Abraham Moles and J. Lequeux (Paris: Dunod, 1960)were signed and dated by the composer (see reproduction in François-Xavier Féron, "Gérard Grisey: Première section de *Partiels* (1975)", *Genesis: Revue internationale de critique génétique* 31 (2010): 77–97). That is why we can state he had in his possession these two books during his residence at the Villa Medici.

(18) Refers to the list of acoustics books given by Grisey during his lessons: Gérard Grisey, "Cours d'orchestration destiné au compositeur," in Grisey, *Écrits ou l'invention*, 203–7.

(19) Fabien Lévy, *Le compositeur, son oreille et ses machines à écrire: Déconstruire les grammatologies du musical pour mieux les composer*, (Vrin, 2013), 58.

(20) Gérard Grisey, "À propos de la synthèse instrumentale," in Grisey, *Écrits ou l'invention*, 35–37.

(21) Grisey, "À propos de la synthèse instrumentale," 35.

(22) For more details concerning this spectral model and the construction of *Dérive*s, see Féron, "The Emergence of Spectra."

(23) Féron, "The Emergence of Spectra," 356.

(24) Gérard Grisey, "Structuration des timbres dans la musique instrumentale," [1991] In Gérard Grisey, *Écrits ou l'invention*, 89–120.

(25) The genesis of this spectral model is addressed in Féron, "Sur les traces de la musique spectrale."

(26) The manifesto by which the name spectral music was accepted was written by Dufourt in 1979 for Radio-France and the Société Internationale de Musique Contemporaine. It was re-published several times, including in Hugues Dufourt, *Musique, pouvoir, écriture* (Paris: Christian Bourgeois, 1991), 289–94. In a letter addressed to Dufourt just after this publication, Grisey claimed to use the adjective liminal rather than spectral (Gérard Grisey, "Lettre à Hugues Dufourt" [July 5, 1980], in *Écrits ou l'invention de la musique spectrale*, 281–82).

(27) Grisey, "Structuration des timbres," 92.

(28) The synthetic spectrum built at the end of *Périodes* is a transposition one octave higher of the original spectral model which contains odd harmonics. Such singularity can be observed in the spectrum of clarinet sounds but not trombone sounds. For more details see Féron, "Sur les traces de la musique spectrale," 411–443.

(29) Program note for *Les Espaces acoustiques* [1993/96], in Grisey, *Écrits ou l'invention de la musique spectrale*, 132.

(30) The Laboratoire d'Acoustique Musicale (LAM—Sorbonne Universités) was renamed the Lutherie-Acoustique-Musique in the 2000s.

(31) The main sketch corresponding to the beginning of *Partiels* is deciphered in Féron, "Gérard Grisey: première section de *Partiels* (1975)": 77–97.

(32) Abraham Moles, *Théorie de l'information et Perception esthétique* (Paris: Flammarion, 1958). This book was included in Grisey's library. Although no date is mentioned, there is every reason to believe that the composer was in possession of this book in the early 1970s.

(33) Michèle Castellengo, *Écoute musicale et acoustique* (Paris: Eyrolles, 2015).

(34) Castellengo, *Écoute musicale et acoustique.*

(35) See Grisey, "Structuration des timbres" [1991], and also the program note for *Les Espaces acoustiques* [1993/96], in which the composer writes: "I indeed analysed with a spectrogram the sound of an E played on trombone and reproduced the main components (the fundamental and harmonics) with *Périodes*'s instruments." Grisey, *Écrits ou l'invention de la musique spectrale*, 131.

(36) François-Xavier Féron, interview with Michèle Castellengo, November 18, 2009.

(37) For further details, see Féron, "Sur les traces de la musique spectrale."

(38) François-Xavier Féron, interview with Michèle Castellengo, November 18, 2009.

(39) François-Xavier Féron, interview with Michèle Castellengo, November 18, 2009.

(40) For more details concerning the operation of this device, see É. Leipp, *Acoustique et musique* and Orcalli, "La pensée spectrale."

(41) Grisey, "Structuration des timbres," 110.

(42) Grisey, "Structuration des timbres," 96–97.

(43) Grisey, "Structuration des timbres," 100.

(44) Commissioned by the Ensemble Intercontemporain in July 1976 and composed for thirty-three musicians in 1976–77, the piece is dedicated to Olivier Messiaen for his seventieth birthday. It was premiered in Paris on March 9, 1978 with the Ensemble Intercontemporain conducted by Michel Tabachnik.

(45) 1000 log (7/5) x ¾ = 110; 1000 log (9/7) x ¾ = 82; and 1000 log (11/9) x ¾ = 65.

(46) Grisey, "Structuration des timbres," 115. Baillet provides a detailed analysis of this part in Baillet, *Gérard Grisey*, 124–132.

(47) Grisey, "Structuration des timbres," 115.

(48) Baillet, *Gérard Grisey*, 124–132.

(49) In order to make this analysis more intelligible, the 40 staves are numbered from top to bottom.

(50) For a detailed analysis of *Prologue*, see Baillet, *Gérard Grisey*, 99–112 and Féron, "Analyse de *Prologue*," 2016.

(51) Baillet, *Gérard Grisey*, 129.

(52) Baillet, *Gérard Grisey*, 131.

(53) Orcalli, "La pensée spectrale," 1547.

(54) Grisey, "Structuration des timbres," 107.

(55) Dufourt, *La musique spectrale*.

(56) Lévy, *Le compositeur*, 58

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