



MUSIC FROM LIGHT

THE REAL MUSIC OF THE SPHERES

HIEROSPHÁNEIA

XAVIER DE PALAU + RAFAEL BALAGUER

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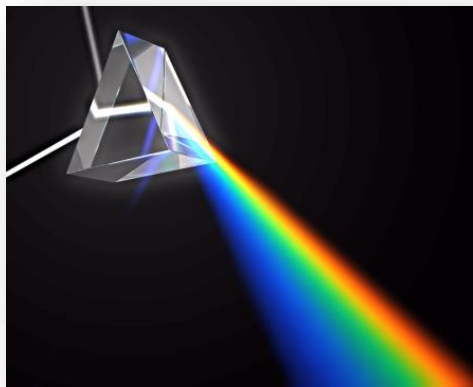
Comet C/2014 Q2 Lovejoy, Rafael Balaguer

Extracting music from light, the real music of the spheres.

1.- About the light, by Rafael Balaguer.

Motivation and reflection.

From its beginnings, spectroscopy was an exciting technique. Newton, in 1672 with his first research on prisms and the decomposition of sunlight, already showed that the white light from our star was composed of a mixture of all the colours of the rainbow. And later, the advances of Fraunhofer in 1815 developing more precise spectroscopes, already allowed revealing the true chemical identity of the Sun and, finally, that of practically any object from which we can capture its light. Thus, indirectly, spectroscopy can define the chemical composition of an astronomical object with great precision. Spectroscopy is, since then, a formidable instrument for the knowledge of the Universe.



Decomposition of the light passing through a prism, Wikipedia, Creative Commons

“Music From Light” brings a new vision to spectroscopy, presenting new methods for the integration of spectroscopy with art. We have learned how to transform light into music. Now, we can compose the authentic music of the spheres thanks to a simple spectroscope, a diffraction grating with which we can decompose the light of any star captured in our observatory. We will present our own version of the sound of light coming from the bodies of the solar system, including the Earth, and from far beyond... How does the sky sound? Uniting science with art, our compositions are not based on music inspired by the stars, but on music extracted directly from the stars, planets, comets, eclipses...

In recent years, in an effort to reunify science with the most social disciplines, it is common for official organisations to publish results with the sound of the stars and other astronomical bodies. Even the sound captured by professional observatories is made available to artists to compose their themes. Our case is different. We have autonomously carried out the entire procedures of spectra capture, processing, and analysis thereof, as well as the elaboration of new and more precise computer algorithms that allow, for the first time, a more precise and comprehensive transformation of an energy manifestation of a visible wavelength, to one with an audible wavelength.

The result is a piece of music truly extracted from the light, with very little human intervention, which is perhaps disturbing, but evocative and suggestive at the same time. It is the authentic music of the spheres, the result of a new transversal vision where art is flooded with science.

One of the engines of this project is undoubtedly the enthusiasm, that innocent enthusiasm that took hold of us from our childhood and encouraged us to seek answers exploring the world. Enthusiasm was equipped with

some of the tools that allow us to approach Nature with a critical eye since prehistory, from the very dawn of our species. These almost magical tools are indisputably science and art. Science, as a mechanism for acquiring knowledge; art as a catalyst for emotions and as a support to socialize knowledge and share it. Knowledge, if we cannot share it, becomes ephemeral and useless.

And in those first moments of human consciousness, there was already this alchemy, this inseparable amalgam for us, between science and art, thanks precisely to astronomy (one of the first sciences) and music (one of the first arts). Astronomy and music are therefore precursors of modern human consciousness, thus becoming conscious beings of the Universe. "Music From Light" pays a humble tribute to those pioneering moments, merging the scientific method with the generation of emotions and feelings emanating from art.

Astronomy is a science that places us, like no other, with total precision in space and time. And the most wonderful thing about this is that thanks to today's technological development, we all can enjoy an unprecedented democratization of access to knowledge. In astronomy, nowadays any interested person can conduct their own research with modest means.

In "Music From Light" we propose to enter into the exciting field of spectroscopy, but with a new objective that adds value to purely astronomical observation and documentation. By incorporating the musical translation of light into our data we will achieve an emotional approach to science.

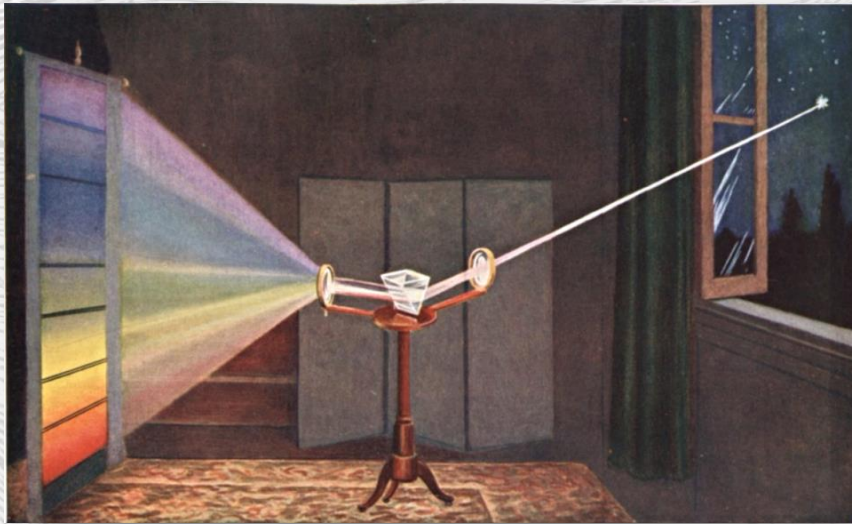
The subtlety of light.

All science lovers have read multiple times about spectroscopy. Spectroscopy has applications in astronomy, physics, chemistry, and biology, among other scientific disciplines. It is an experimental analytical technique that is based on detecting the absorption or emission of electromagnetic radiation from certain energies, and relating these energies to the energy levels involved in quantum transitions of the substance to be detected. In this way, quantitative or qualitative analyses of a huge variety of substances can be done, taking advantage of the ability to emit or absorb radiation of a certain wavelength presented by these, or some product formed from them.

Historically, spectroscopy originated through the study of visible light dispersed according to its wavelength, for example by an optical prism. The concept was later greatly expanded to cover any interaction with radiative energy as a function of its wavelength or frequency. Spectroscopy data is often represented by a spectrum, an intensity distribution diagram based on wavelength or frequency. Spectral analysis is based on detecting the absorption or emission of electromagnetic radiation at certain wavelengths, relative to the energy levels involved in a quantum transition.

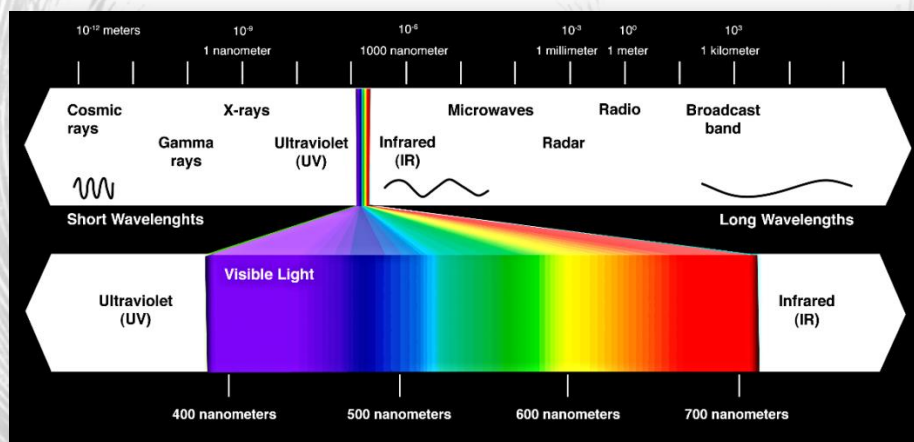
Since ancient times, scientists and philosophers have speculated about the nature of light. Modern understanding of light began with Isaac Newton's prism experiment, with which he found that any incident beam of white light, not necessarily from the Sun, decomposes into the rainbow spectrum (red to violet). Newton had to strive to show that colours were not introduced by the prism, but were really the constituents of white light. Subsequently, it was possible to verify that each colour corresponded to a single range of frequencies or wavelengths.

In the eighteenth and nineteenth centuries, the prism used to break down light was redesigned by adding slits and telescopic lenses thus obtaining a more powerful and accurate tool to examine light from different sources. Joseph von Fraunhofer, an astronomer and physicist, used this initial spectroscope to discover that the spectrum of sunlight was divided by a series of dark lines (later called absorption bands), whose wavelengths were calculated with extreme care. In contrast, the light generated in the laboratory by heating gases, metals, and salts showed a series of narrow, coloured, and bright lines on a dark background (emission bands). The wavelength of each of these bands was characteristic of the element that had been heated. At that time, the idea arose to use these spectra as a fingerprint of the observed elements.



Decomposition of light as it crosses a prism showing absorption bands on a spectrum of a star, Wikipedia, Creative Commons

All stars, as well as interstellar matter, emit electromagnetic waves. The visible light, the portion of the electromagnetic spectrum that humans are able to see, is very small compared to the other spectral regions. This region, called the visible spectrum, comprises wavelengths from 380nm to 780nm. The human eye perceives the light of each of these wavelengths as a different colour, so in the decomposition of white light at all its wavelengths, by prisms or by the rain in the rainbow, the eye sees all colours.

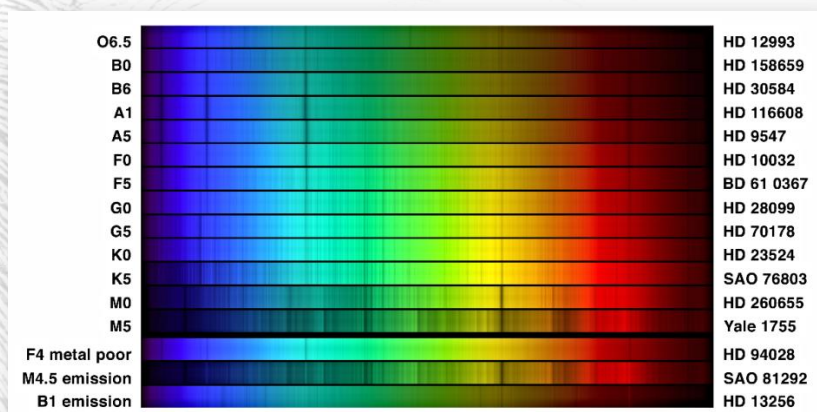


Electromagnetic spectrum indicating the wavelengths of each radiation, Wikipedia, Creative Commons

The light we receive from a star, for example, contains a mixture of radiations, some of which come from hydrogen atoms, helium, iron, etc. If that light is passed through a slit to obtain a long, narrow beam, and if it passes through a prism, the different radiations will be classified, as the prism diverts to one end the longer wavelengths (corresponding to the red light) and to the other the shorter wavelengths (violet light); between the two ends the intermediate-length waves will be ordered: orange, yellow, green, blue and indigo. This results in a continuous spectrum whose appearance is that of a narrow cross-sectional strip of rainbows.

Between the emission of that spectrum by matter excited by the heat of a star (for example) and its reception on Earth there is another important phenomenon, which is the one that allows spectral analysis. Each time an

emitted radiation finds, during its spread in the same atmosphere of the star, a vapour containing atoms of the same element, the radiation is absorbed by one of these atoms. Therefore, in the spectrum of that star to be obtained on Earth, each of the places corresponding to the intercepted wavelengths will be lacking in light and a dark streak will appear on it. Thus, you will get an absorption spectrum that will contain in the form of stripes the traces of all the chemical elements existing in the star, and you can classify the stars according to their spectral class (O, B...).



Classification of stars according to their spectral class. On the left the spectral classes are shown, on the right the spectra of some representative stars of each class are identified, Wikipedia, Creative Commons

In addition to indicating the elemental composition of the light source and the physical state of its matter, the spectrum reveals whether the luminous body and Earth are approaching or moving away from each other, and also indicates the relative speed of this movement. When comparing the stripes of the spectrum of a star with those of a terrestrial light, it is observed that in the stellar spectrum the stripes are shifted slightly towards the red end of the spectrum or to the violet colour. This phenomenon, due to the Doppler-Fizeau effect, allows calculating the radial velocity with which the star moves away from Earth or approaches it. In particular, it has made it possible to discover that most galaxies move away from each other, which is proof of the expansion of the Universe.

There is always a more intense radiation zone in the spectrum of stars than the others. This preponderance is independent of the chemical composition of the star and results from the star's surface temperature. Based on the spectra, it has been possible to find out the surface temperature of the stars and classify them into groups, in the so-called Hertzsprung-Russell diagram, dividing the stars according to their temperature and luminosity, which also allows us to infer their age.

But the importance of spectroscopy goes much further. Thanks to the spectral analysis of celestial bodies it has been revealed that they are all composed of the elements we know here on Earth and are listed in the periodic table of elements, the basis of the constructive matter of the Universe is the same throughout Cosmos.

Chasing spectra.

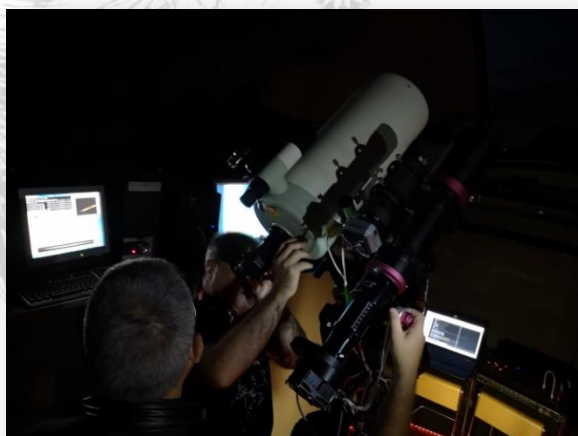
For anyone with a scientific vocation (science is an attitude to life), current astronomy is a special motivation. Changing theoretical reading to real action is always an exciting opportunity that we should not let pass, and thanks to spectroscopy we can take action and turn our observations into true science.

This project started in 2015 and the truth is that, as such, it will never have a definite end, since we can get spectra and music from any celestial body at any time, such as when bright new comets visit us. The main objective of the work is to chemically characterize the observed stars and transform that information into an

audible experience. On a personal level, the thrill of seeing the famous "Fraunhofer's bands" directly with your own eyes is absolutely unforgettable. It is this emotion that drives us to share this experience in a cross-cutting project, merging art and science.

For the capture of the spectra analyzed for "Music From Light" we have counted on the support and equipment of Astrogirona, Girona Astronomical Association. We have used telescopes and cameras located in the observatories "Can Roig MPC C99"; "Albanyà MPC L17" and also Rafael Balaguer's observation equipment. The observations have been made in Llagostera, Albanyà and Rocafort in Catalonia, Spain, and also in Glendo, Wyoming, USA, using the equipment and methodology described below.

The telescopes used have been a Takahashi Mewlon, a magnificent Cassegrain reflector with Dall-Kirkham optical design, 210mm in diameter and 2415mm focal length, f/11.5; a Meade LX200 ACF, an aplanatic Schmidt-Cassegrain catadioptric, 254mm in diameter and 2500mm focal length, f/10; and a 406mm diameter, 3251mm focal length Meade ACF, f/8. Advanced Coma Free (ACF) equipment combines multiple technologies to produce highly proven distortion-free images with true colour image delivery across their entire flat field of view. Exceptionally, a Fuji Finepix S7000 bridge camera was directly used as an optical system to capture the solar corona spectrum of the solar total eclipse on August 21st, 2017 from Glendo, Wyoming, USA; and the spectrum of the earthshine on the Moon from Rocafort, Catalonia, Spain. The telescopes have been used on the computerized mounts Gemini G42, Meade LX200 SmartMount, Skywatcher EQ8, and 10Micron GM3000 HPS.

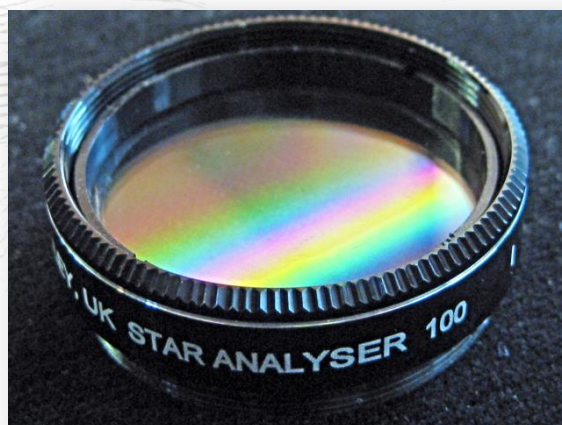


Obtaining and processing spectra at the Can Roig MPC C99 Observatory, Jessica Lleonart

Various cameras have been used to capture the images, the one already mentioned Fuji Pinepix S7000; and the following have been used connected to telescopes: QHY5 colour, CMOS; QHY9 monochrome, CCD; ATIK 161C colour, CCD; Philips Toucam Pro II Colour, CMOS and Moravian G4-9000 Mono, CCD. CCD cameras are much more sensitive and suitable for studying weaker, more distant objects, such as stars or nebulae. CMOS, with their lower sensitivity, are more often recommended (because they become less saturated and allow long video exposures) for the observation of brighter and closer objects, such as the Moon, the Sun, and the planets, as well as some comets.

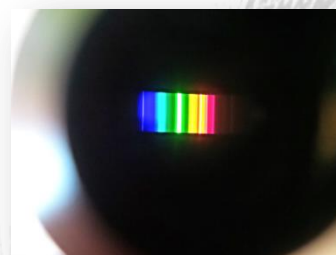
To break down the light of the stars and obtain their spectra we have used low-cost and affordable systems for any astronomy enthusiast. The main device is a Paton Hawksley Spectroscope Star Analyser 100 diffraction grating, which features a high-efficiency design with 100 lines/mm. This is the most important element of the assembly needed to capture the spectra. It is an optical component with a regular pattern, which diffracts (divides) light into several beams. The direction of these beams depends on the spacing of the grating and the

wavelength of the incident light, so the grating acts as a dispersive element. It is directly screwed into the coupling of the cameras to optical systems, either a telescope or a photographic lens.



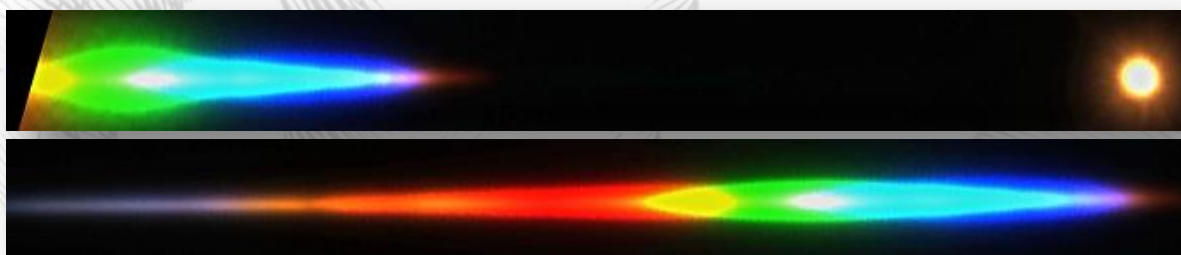
Diffraction network Paton Hawksley Spectroscope Star Analyser 100, Paton Hawksley UK

As a curiosity and as an exception, a Shelyak handheld spectroscope, which has a diffraction grating of 600 lines/mm, has been used to obtain the spectrum of the Sun.



Left: Shelyak handheld spectroscope, Shelyak. Center: Spectrum of the Sun, Rafael Balaguer. Right: spectrum of a 40W incandescent lamp, Rafael Balaguer

Once we have selected the object to be observed and located correctly in the sky with total precision thanks to the control programs of the telescope that we have in the observatories, and also in the field, we check that the diffraction grating deploys to the left and right of the observed object its spectrum. At this point, we proceed to centre the spectrum in the centre of the camera's field of view, and we will take a video stream if we use a CMOS camera, or take a picture if we use a CCD camera. An exposure time of about 20-30 seconds in all cases will be more than enough.



Vega star's spectrum obtained with a colour CMOS camera, Rafael Balaguer

If we have taken a video stream we will process it with the free RegiStax or AutoStakkert! software. This is a process we call "to stack". This way you get a single image, but it is an image that accumulates useful information from many frames.

We do this to optimize the information by improving the signal-to-noise ratio, where the "signal" represents the actual characteristics that we want to keep in an image.

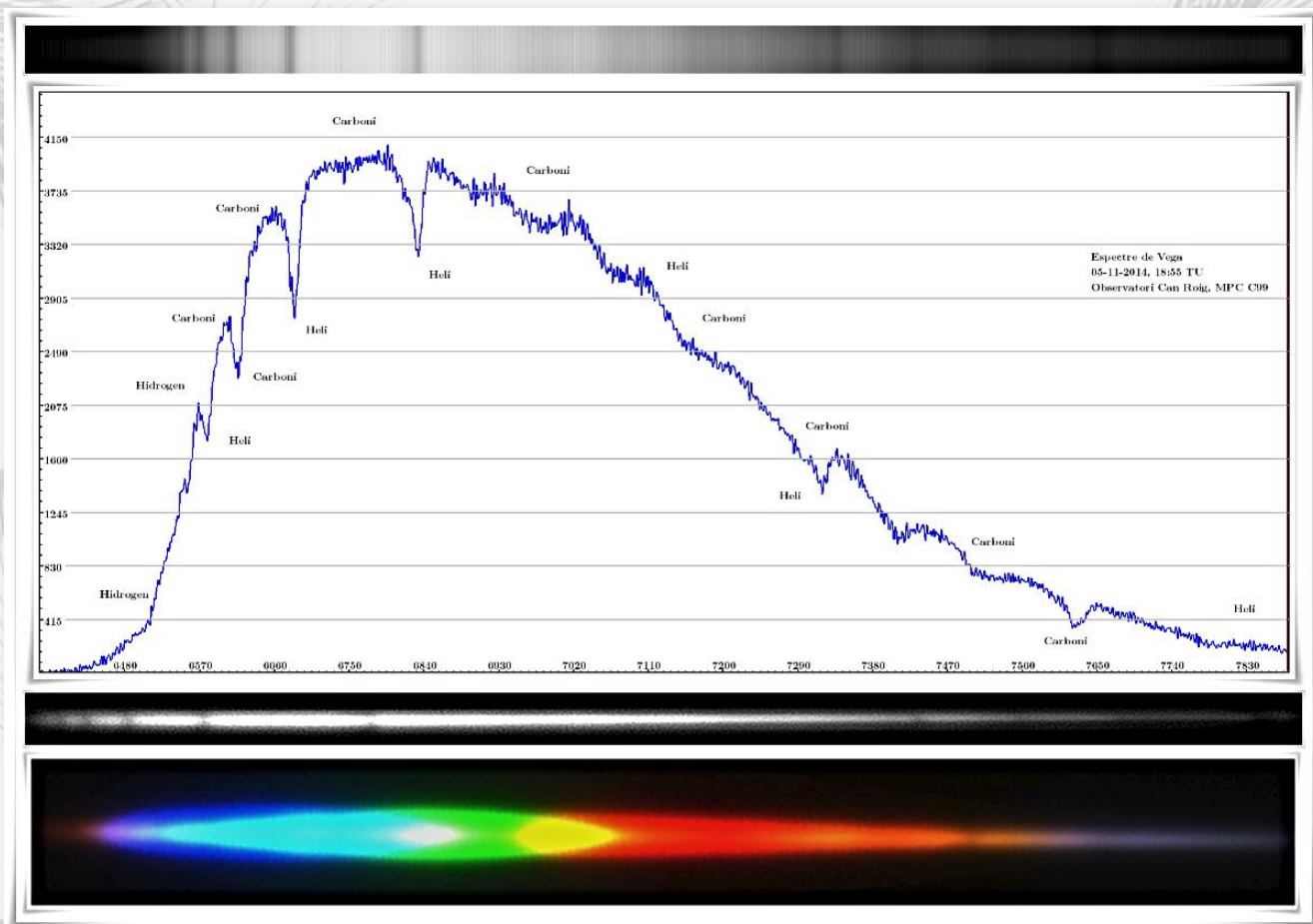
If you have taken several individual photographs you can also stack them, but it is not essential, because with a single sharp photograph of the spectrum you can work properly.

Once we have obtained the image with which we will finally work, we proceed to crop it with any photo editor and preserve only the region of the photograph that shows the spectrum, and we will rotate it conveniently so that we always have a horizontal image, without other elements other than the spectrum itself, and with the red colour of the spectrum aligned to the right end of the image.

This image will be the one that we will open with the free Visual Spec spectral analysis software.

The first step will be to adjust the brightness and contrast of the image, so that we can get the best possible definition of the absorption bands.

Then, from this image, the program creates the graph that is extracted from the spectrum. This graph represents the intensity of each pixel that corresponds to a specific wavelength expressed in Angstroms.



Vega's spectrum already oriented correctly and processed with free Visual Spec software, Rafael Balaguer

The next step is to calibrate the spectrum. When calibrating the spectrum, you are looking to associate a wavelength with each pixel and therefore know the intensity of each wavelength. To do this, you need to identify two lines of the spectrum and enter their wavelength. To identify them, what we do is comparing the spectrum with another one where you already have this information. This other spectrum is called the "reference spectrum". Usually, the reference spectrum is recorded at the same time as the spectrum of the observed object, placing a lamp of some element such as sodium in front of the telescope. Since we do not have this type of calibration lamp, we have used synthetic spectra of different elements provided by the software itself as a reference. Once the two lines are identified, the same software interpolates the relationship to the other pixels.

If the observed object is a star, once the spectrum is calibrated it is readjusted taking into account Planck's law, which tells us that the heat produced by the object itself also influences the wavelengths of the radiation it emits. To do this, we look for the type of star that we are processing in the software's own guide and then the software adjusts it itself. It is also very important for the reliability of calibration of different spectra to take the captures in the same night.

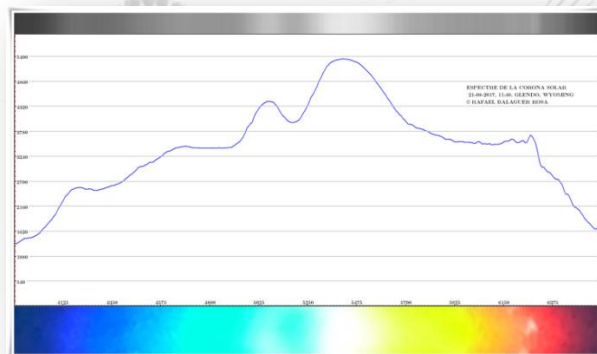
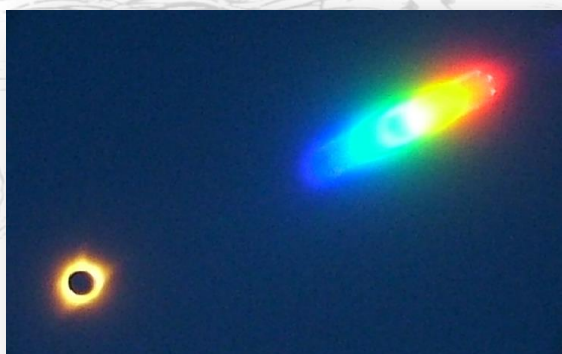
Once we get the calibrated spectrum, we can obtain two series of data, which we will export in text file format, **.txt*. The first series informs us of all the wavelengths that appear in the analysed spectrum in relation to the pixel intensity. The second series documents all the chemical elements that emit at similar wavelengths and that could correspond to those obtained. For this second series to be correct, we must tell the software what kind of spectrum it is, whether that of a star, a chemical element, the Earth's atmosphere, a planet, comet...

.spc	pixel	angstrom	intensity	Ref1	Ref2
1	6553.14404296875		995	995	0
2	6554.24609375	1426	1426	0	0
3	6555.34814453125		378	378	0
4	6556.4501953125		1243	1243	0
5	6557.55224609375		1012	1012	0
6	6558.654296875	973	973	0	0
7	6559.75634765625		1024	1024	0
8	6560.8583984375		1278	1278	0
9	6561.96044921875		802	802	0
10	6563.0625	1024	1024	0	0
11	6564.16455078125		1016	1016	0
12	6565.2666015625		970	970	0
13	6566.36865234375		1124	1124	0
14	6567.470703125	1112	1112	0	0
15	6568.57275390625		1071	1071	0
16	6569.6748046875		966	966	0
17	6570.77685546875		1072	1072	0
18	6571.87890625	1002	1002	0	0
19	6572.98095703125		933	933	0
20	6574.0830078125		1030	1030	0
21	6575.18505859375		1038	1038	0
22	6576.287109375	967	967	0	0
23	6577.38916015625		999	999	0
24	6578.4912109375		990	990	0
25	6579.59326171875		963	963	0
26	6580.6953125	963	963	0	0
27	6581.79736328125		974	974	0

Part of exported data from Vega's spectrum already processed, Rafael Balaguer

The chemical elements found in the studied stars produce mostly absorption lines, so to know their chemical composition we can determine the wavelength of the absorption bands. To do this, using the tools of the software itself, we can find the line centre of each valley in the spectrum graph. So we can then identify which chemical element that particular wavelength corresponds to.

Since 2015 we have gathered a very large amount of data, analysing a multitude of objects, stars, nebulae, comets, including the impressive C/2020 F3 (NEOWISE); and some very unusual spectra such as the spectrum of a Moon eclipse; the spectrum of the weakening of the star Betelgeuse; the spectrum of the solar corona, obtained in the total eclipse of the Sun of August 21st, 2017; or the spectrum of the Earth.

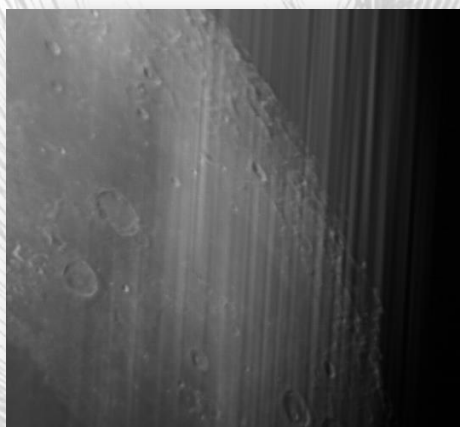


Photography and processing of the solar corona spectrum during the total eclipse of the Sun on August 21, 2017 in Glendo, Wyoming, USA, Rafael Balaguer

The spectrum of the Earth is unique. To obtain the spectrum of the Earth on our own, we had to be able to capture its light and analyse it. Obviously, this was a huge problem, of impossible solution for us, because without being able to count on the possibility of observing Earth from space with our modest diffraction grating and our telescopes, we could only count on spectra obtained by space missions to sonify our planet.

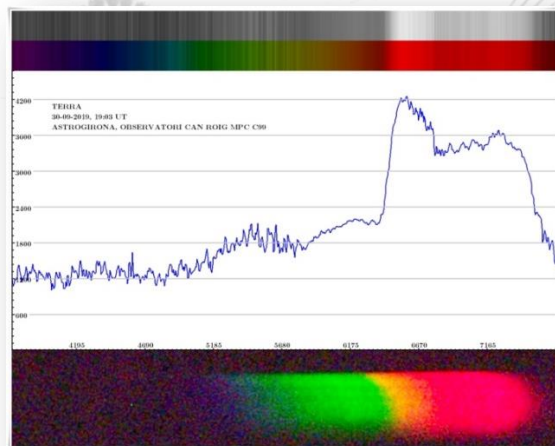
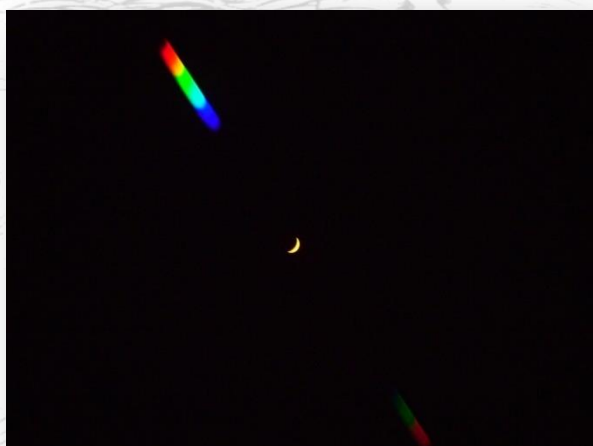
But not everything that seems impossible ends up being so. Reflecting on how we could observe the light emitted by Earth without leaving our planet, we remembered that there is one way to do it: we only had to observe the Moon! It's about observing what we call "earthshine". Earthshine or Moon's ashen glow is the weak light that illuminates the part of the lunar disc not bathed by sunlight, without which it would be invisible from Earth. This faint illumination of the dark part of the Moon corresponds to the light coming from the Sun that reflects the Earth's illuminated surface. It is especially noticeable during the first and last days of the lunar cycle, when the part of the Moon illuminated by the Sun observable from Earth is very small or imperceptible, or if the Moon is in the phase of the new Moon. Then, almost the entire Earth disc visible from the Moon is bathed by sunlight and reflects some of that light towards our satellite.

By obtaining the spectrum of the Moon's ashen light we could analyse the spectrum of the Earth, and thus finally hear the sound of our planet without having to go out into space. To obtain this elusive spectrum we must subtract the Moon's spectrum from the earthshine's light spectrum, thus obtaining the signal corresponding to the Earth's spectrum.



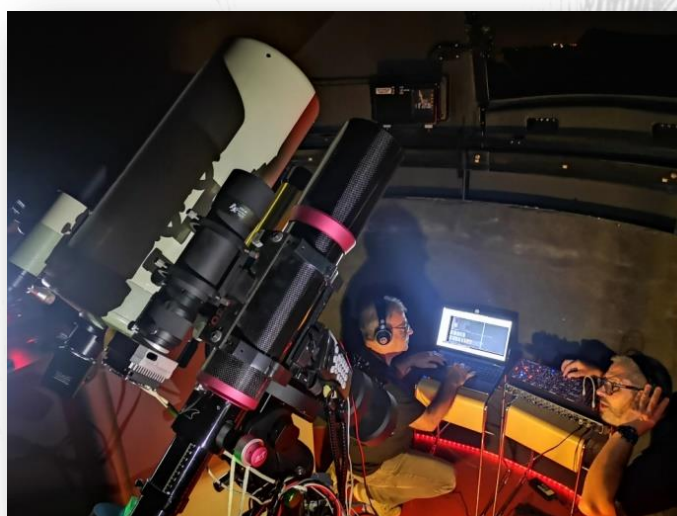
Moon's spectrum, Rafael Balaguer

We already had several spectra of the Moon, which are different depending on the area studied and the image resolution used, so finally making the necessary adjustments we were able to hunt the spectrum of the Earth. It is a solution as simple as elegant!



Photography and processing of the earthshine's spectrum (spectrum deployed at the bottom of the image), Rafael Balaguer

With the information of each complete spectrum, exported from raw format, in *.txt files, we can now proceed to the last phase of our project: transforming the light into music, normally obtaining a musical theme from each spectrum, with the exception of Moon's instrumental piece, which incorporates information from different spectra.



Real-time listening to the sonification of processed spectra at the Can Roig MPC C99 Observatory, Jessica Lleonart

In this new cross-cutting approach, we are pioneers in developing new methodologies and algorithms to make this process a scientifically valid system that goes far beyond the simple mathematical curiosity generated by the simple sonifications that were obtained with the first versions of the Visual Spec software.

We have managed to hear the light, integrating various disciplines, from astronomy to mathematics and computing, with music as a link.

Our development can also bring an unexpected scientific return, as the power of the new algorithms can be an important advance in astrophysics studies carried out by blind scientists. Thanks to this expanded deployment

of the analysed spectra, an even more precise fine-tuning of the nuances of volume, rhythm, tone, and timbre is possible. Using sound allows you to discover more information than you get only by viewing the data. In this way, the sonification method, in addition to helping non-seers, can support astronomers in general to discover variations in patterns that are otherwise very difficult to detect.



Rafael Balaguer and Xavier de Palau working at the Can Roig MPC C99 Observatory, Jessica Lleonart

2.- About music, by Xavier de Palau.

The Harmony of the Universe.

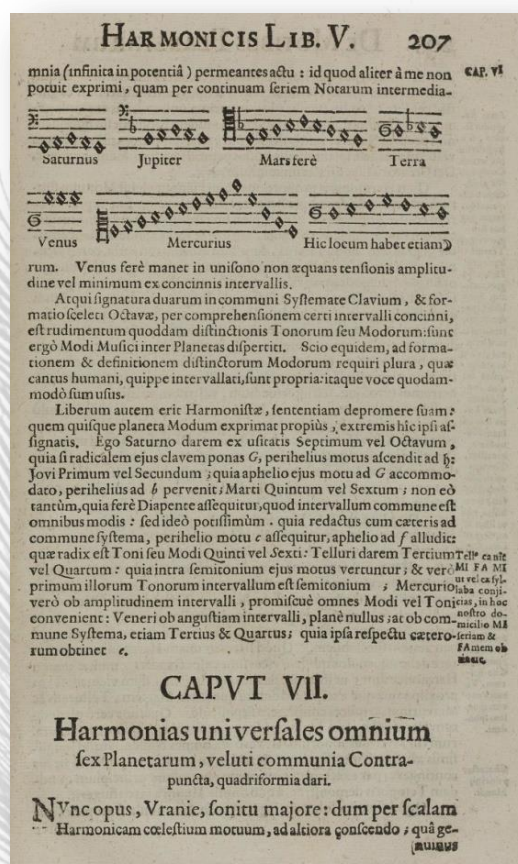
Since the awakening of human consciousness, at the dawn of humanity, the attraction to heaven is perceived in all cosmogonies. Stars shape civilizations over time as they move majestically through the sky, crafting their myths and legends.

More than two thousand and five hundred years ago, in ancient Greece, music was the key to deciphering the laws governing the behaviour of celestial bodies. This tool would allow us to understand matter, medicine, time, and stars, thus encompassing all universal knowledge.

Plato, in Timeo's texts, describes how the Soul of the World was forged by the Demiurge, dividing the primordial substance into harmonic intervals. Pythagoras conceived the Universe as a great monochord, with a single string connected by the upper end with the pure spirit and by the lower end with matter, a string to unite Heaven and Earth.

For ancient civilizations, this *kosmos* was something tidy, regular, and predictable, being its music elegant and perfect. Consequently, knowledge of the truth would be revealed through it, being the way to identify the mysteries of man and the Universe.

Throughout history, we see how shamans, kings, priests, and philosophers used the celestial order and its music as a vehicle to enter deeply into the transcendent. This harmonious pattern gave meaning and a pretext to human existence, transcendence beyond the everyday and chaos, helping to understand and humanize the Universe. In this tradition, there are thinkers such as Homer, Aristotle, Pythagoras, Plato, Ptolemy, Boethius, Al-Hassan Al-Katib, Gioseffo Zarlino, Kepler, Kircher, Newton and Rameau, to name just a few.



First edition of *Harmony of the World*, by Johannes Kepler. The page contains the musical scale that Kepler attributed to the six well-known planets at that time, and the Moon, which describe their orbital movement, 1596, Wikimedia Commons

However, modern science has shown us a universe contrary to a geometry designed by gods, balanced, immovable, and perpetual. It is an inhospitable, mutable, chaotic, uninhabitable, and hostile place for humans. It doesn't need us.

Devastating explosions, destruction, and continuous creation. Gargantua devouring entire worlds, deadly radiation, and unimaginable forces. This would be the real music of the Cosmos.

Science seeks patterns within this apparent randomness, hoping to find the truth and laws to support it. Art is content with protecting us from this chaos, reducing its dimensions, and providing us with a sense of achievable organization. Artistic creations, without providing us with beauty, protect us from chance, taking it to a more human and understanding dimension.

Art and science complement each other, they are the two poles that maintain the balance of human thought, giving meaning to life.

"Music From Light" is a flash of light in time transformed into sound. Its harmonic fabric is not defined, there is no absolute tonal hierarchy. Only one possible field of attraction to a tonic that would come from the mean wavelength of the star is sensed. Presented as a pseudo-random structure, it is more reminiscent of the avant-garde atonal musical forms of the twentieth century.

Despite their atypical structure for our ears, the soundscapes generated are certainly exotic and beautiful.

We are pleased to present a journey into another reality of the Cosmos - perhaps we only softly touch it - through the sense of hearing, built on the foundations of the science of spectroscopy and astronomy, as well as the use of modern technological tools: telescopes, computers, and synthesizers.

Sonifying the Cosmos, a brief methodological summary.

The art of sonification is the act of converting into sound any idea or physical object that can be represented numerically. For example, the pixels of a digitized image, the measurements of an electrocardiogram, the statistical data of a sample, the temperatures of climate change over the years, the demographic values of a population, real-time Internet searches, would be some of the many possibilities to choose.

Thus, "Music From Light" is the result of transforming spectroscopy data obtained from different celestial bodies into sound.

However, this working method can cause what we call pareidolia in the image; that is, to see faces where there aren't.

Extracting a numerical pattern that gives us beauty from stars while not manipulating the captured data of the object is not an easy task. The transformation algorithm should be both elegant and true to scientific data as much as possible.

Naturally, there are many ways to process the data. Each of these has a very different musical result, sometimes causing beautiful melodies and sometimes horrible sounds. This forced us to work for many months on the development and testing of the ideal algorithm, polishing it through the hits and the many errors.

In reality, not a single transformation method was finally chosen, but several simultaneously. This has allowed such methodologies to be executed synchronously, to achieve a dense and multichromatic texture that, together with atonality and an indefinable rhythmic pattern, creates extremely rich, hypnotic, and relaxing futuristic pure fantasy landscapes.

Basic frequency of stars.

The most logical and elemental sonification is to transpose the wavelength of light at a given frequency and, once obtained, transport the necessary octaves proportionally so that the sound does not surpass the human

auditory range. Remember that a musical note emitted by any instrument is a frequency of wave patterns, like the rest of the electromagnetic spectrum waves (radio, visible light, x-rays, etc.).

The spectroscopy data for each star presents us tables containing each of the intensities of the many wavelengths captured by the observatory's cameras. All we have to do is transform the wavelength expressed in Angstroms into frequencies.

So basically:

$$f = c/\lambda$$

Being c the speed of the light (approximately 3×10^8 m/s), f the frequency and λ the wavelength. ($1 \text{ \AA} = 1 \times 10^{-10} \text{ m} = 0.1 \text{ nm}$).

Once the frequency has been obtained and transported to the audible range, it can be transformed to an integer corresponding to the value of a MIDI (*Musical Instrument Digital Interface*) note. In this way, we can create tracks in standard MIDI file format (*.smf) or send it directly to a synthesizer or electronic instrument that accepts this protocol, complying with the tuning of our tempered scale, the most frequent and standardized.

The frequency transformation to MIDI note would be:

$$\text{midi note} = 12 * \log_2(\text{frequency}/440 \text{ Hz}) + 69$$

The amplitude of the sound wave is assigned to the corresponding intensity of each wavelength; that is, the volume between a range of 0 to 127, which would be the possible values within the MIDI standard.

However, several problems arise with this method that need to be considered.

The first would be that if we sent the obtained frequencies directly to an oscillator without converting them to MIDI note, the changes between values would be so small and they couldn't be perceived by most listeners.

Our sense of view allows us to discern very small wavelength differences within the visible spectrum, allowing us to distinguish colours. On the other hand, our sense of hearing is much more stubborn and does not perceive these tiny changes. Most people do not distinguish an eighth of tone (3 to 5 Hz distance between notes); only the most trained ears can distinguish these subtle microtonal variations. At lower values it would be virtually indistinguishable.

Another problem would be that applying the MIDI transformation to avoid these tonal mismatches would result in countless repeated notes. The resulting effect would be monotonous and boring music. In addition, all stars move between the same areas of the scale and at a very similar distance between intervals: a major second, at most a major third. We see that most celestial bodies have only one or two notes during their execution.

However, we do not rule out the transformation of wavelength into frequencies, and these in MIDI, so that we can add a new audio track as a background sound for each star, with its personal seal: the base frequency. As if it were a background noise of the Universe or a support container for each celestial body.

Playing with intensities and time.

To avoid the monotony of the "base frequency" method, we use the intensity values as notes instead of as volumes. The wavelength would correspond to the timeline.

For the transformation of the light scale into auditory frequency scale, we use a mapping between the minimum and maximum wavelength intensity values along with the minimum and maximums of the audible sound.

An analysis is first performed between the maximum and minimum peaks of the intensity data provided by the observatory and, once obtained, is mapped as follows:

$$I_{max} - I_{min} \rightarrow F_{max} - F_{min}; I - I_{min} \rightarrow Hz$$

Being I_{max} = maximum wavelength intensity, I_{min} = minimum wavelength intensity, F_{max} = maximum audible frequency, F_{min} = minimum audible frequency, I = intensity to be converted, Hz = obtained sound frequency.

Once we have the frequency, it becomes a MIDI note following the above method.

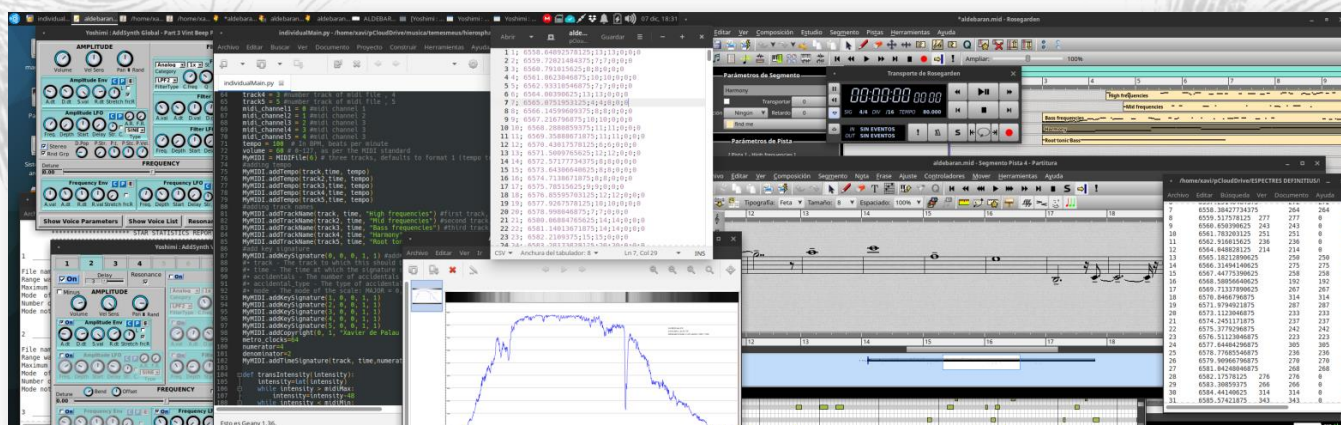
To place these notes in the timeline, the wavelengths are analysed *a priori*, with the minimum for the time 0 and the maximum for the final value.

The maximum duration of this timeline is limited to 2-3 minutes, with sixteenth note being the smallest quantization unit.

In case several consecutive equal notes appear they are linked forming a more varied duration of notes (whole note, half note, quarter note, eighth note, etc.).

To better adapt the time to the agreed minutes of duration, the tempo (beats per minute, *bpm*) is modified to the corresponding speed so that the proportions between the values of the musical figures do not change.

In order to better analyse and distribute the resulting notes, they are separated into three audio tracks: treble, midrange, and bass notes; which would be equivalent to soprano, tenor, and bass in classical music.



Computer and musical analysis, Xavier de Palau

Statistical-based harmony.

One last algorithm analyses all the resulting and saved notes in the second audio track.

These "melody" notes are extracted from the timeline in fragments proportional to density by fraction of time or pulsations and analysed later. The most significant notes are chosen based on their duration and repetition and, by checking the result, the tonal degree of each fragment is determined.

Of course, since this algorithm does not have the behaviour of a human composer, cadences, accents, phrases, etc. are indistinguishable and a typical or classical harmonization is not possible, so we chose to only use the statistical analysis.

To avoid problems with possible out-of-tone notes, only the fundamental chord is executed.

Music, maestro!

In the final stage, a sequencer is responsible for reading and running the MIDI file. The timbre of the instrument interpreting this "score" has been chosen completely arbitrarily since the observatory data does not provide us with any reference about it.

To do this, a multitimbral synthesizer capable of simultaneously executing the different MIDI tracks of the resulting file (1 for the background, 1 for the harmony, and 3 for the melodies separated by its heights) has been used. Three synthesis methods combining additive, subtractive, and Fourier are used for sound generation, as well as other synthesis methods. No external samples are used to produce the sounds, everything is elaborated with synthesis. Except for the Moon which, due to its special value and symbology, and seeing that the resulting melody seems composed rather by a human than a celestial object, we opted to use a female voice sampled in the main melodic lines. Please excuse us for the use of this little artistic license.

For the automatic execution of reading the observatory data files, transforming light into notes, and writing the MIDI file, our own software has been developed and adapted to the demands of our project.



Sonification studio, Xavier de Palau

3.- About us.

Hierospháneia.

Purist version of the term "hierophany" (from the Greek *hieros* (ἱερός) = sacred and *pháneia* (φαίνειν) = to reveal, to bring to light); is the act of manifestation of the sacred, also known among Hindus and Buddhists with the word of the Sanskrit *darsana*, and, in the most concrete form of the manifestation of a god, deity or *numen*, is called theophany.

A hierophany is a manifestation of sacred forces in which what is shown is not God in a personal sense, but rather the sacred sense of the Cosmos, the profound value of the spirit of divinity that fills everything.

The term was coined by Mircea Eliade, in his work "Treatise on the History of Religions", to refer to an awareness of the existence of the sacred, when it manifests itself through the objects of our usual Cosmos as something completely opposed to the unholy world.

In order to translate the act of manifestation of the sacred, Eliade proposes the term "hierophany", which is very concrete, since it refers only to that which corresponds to the sacred that is shown to us.

Hierophanies can be simple or complex. Simple ones are when manifested through objects, such as a stone, ring, sword, or river. Complex ones occur when they manifest themselves through a complex and long process, for example, the emergence of a religion.

For Mircea Eliade every hierophany, from the simplest, it's a paradox because when this manifestation happens through a sacred object it does not lose its unholy nature. Hierophanies are experiences of people full of faith, accompanied by admiration, stupor, or terror that borders on the ineffable.

Hierospháneia are Xavier de Palau and Rafael Balaguer, who have been collaborating on several multidisciplinary projects since 2011.

Website: <http://www.hierosphaneia.com>

Facebook: @hierosphaneia <https://www.facebook.com/hierosphaneia>

Twitter: @hierosphaneia <https://twitter.com/hierosphaneia>

Instagram: @hierosphaneia <https://www.instagram.com/hierosphaneia/>

YouTube: https://www.youtube.com/channel/UCdBMMKxl3y_9EBQpxKq2g2Q

Xavier de Palau.

With a classical and scientific musical training, Xavier de Palau (Girona, 1962) is a transversal artist.

A restless-minded musician and composer, a constant innovator, he is always open to the search for new creative horizons. He uses science and new technologies as tools that allow him to open different experimental fields in electronic music and algorithmic composition or sonification. Passionate about interdisciplinary knowledge, he has worked on his music within different fields such as astronomy, cryptography and numerology, poetry, image and photography, history, biology, or gastronomy.

Recent work:

«**Peccata Mundi Project**» (2006-2009). Project that deepens into algorithmic composition (without human intervention) based on chaotic systems. It is a musical and mathematical experience that turns sensations into sounds. Presented at the gastronomic fairs of Barcelona (2008) and Girona (2009), and at the "Nit de Recerca '09" (with the collaboration of the University of Girona).

«**Divertimento 1.0**» & «**Divertimento 2.0. Evolució**» (2011-2013). Multidisciplinary shows that combine dance, poetry, and music with science and technology. Music generated from light, the human genome, and the movements of extremophiles in a video game, astronomy, and stochastic processes. Presented in Llagostera and Banyoles, Girona (with the collaboration of Quim Bertran: theremin and synthesizers, Albert Pons: poetry and selection of texts, Aïda Jordà: dance, Carles Avilés and Jordi Rull: images, script and representation of a dramatization of the Darwinist debate and support in live performance, Rafael Balaguer: scientific texts, Isaac de Palau: construction and design of the Chromachine in addition to the source code and design of the video game).

«**Deu anys sense tu**» (2013). Music composed in homage to Miquel Martí i Pol in the form of a multidisciplinary show based on the work of the Catalan poet. Presented in Sant Celoni (Barcelona) during the 10th anniversary of his death (with the collaboration of Aïda Jordà: dance, Albert Pons: poetry, and Quim Bertran: synthesizers and theremin).

«**Sur l'écran japonais**» (2013-2014). Music inspired by Junichiro Tanizaki's "In Praise of Shadows" presented, in the form of an author's book, in Barcelona and Sant Celoni in 2014 together with the French writer Michel Butor ("*poèmes*") and the plastic artist Marti Pey ("*decoupages*"). (CD Edition).

«**L'univers no està en silenci**». Research in radio astronomy and experimental music based on the sounds generated from radio signals emitted by the planet Jupiter. Presented in Llagostera and Barcelona in 2015 together with Rafael Balaguer (astronomer and scientific disseminator).

«**Oradura**» (2014 - 2015). Work with an aesthetic inspired by the work of writer H.P. Lovecraft. Music that includes cryptography, numerology, and psychoanalysis. Presented at the castle of Palol de Revardit, Girona, in 2015, together with the work of the plastic artist Carles Avilés. (CD Edition).

«**(fre)Quències**» (2015-2016). Generation of music from the celestial vault in real time and geolocation. Presented at the show "Espheres" of the dance company Moviment Lantana at the astronomical observatory of Batet de la Serra (Olot, Girona) within the framework of the International Dance Festival of this city.

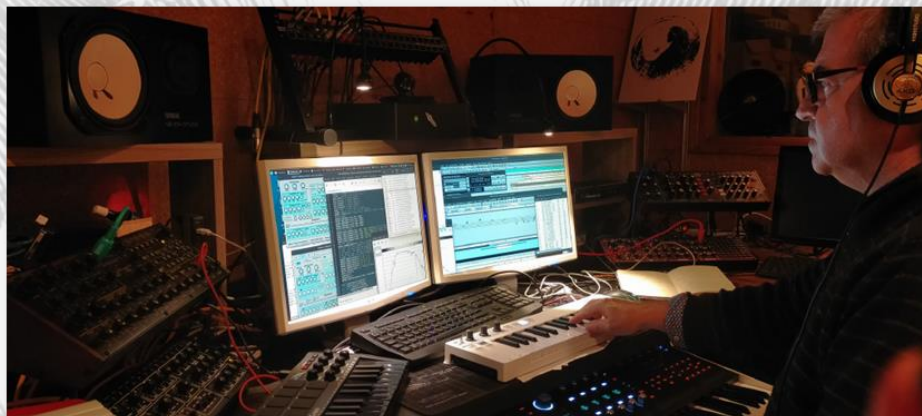
«**Silentium**» (2015-2016). Work in collaboration with photographer artist Anna Bahí, presented in the form of a limited edition art book. Music inspired by the walls of the Medieval Hospital of Santa Maria della Scala (Siena) in an introspective reflection on silence and the human psyche. Presentation at: Istituto Italiano di Cultura (Barcelona), February 2017; Fundació Vila Casas, Palau Solterra (Torroella de Montgrí, Girona), February 2017; Complesso Museale Santa Maria della Scala (Siena, Italy), September 2017, and at Fundació Lluís Coromina (Banyoles, Girona), May 2018. (CD Edition).

«**Els Cavalls de Stenon**» (2019). Soundtrack for a great epic adventure that began millions of years ago, an idyllic and wild moment carved by natural selection: prehistory. A personal vision of chants, dances, visions, and myths of those children from the African forests. Presented in conjunction with the novel "El Darrer Clan. Els orígens" by the writer Joan Anton Abellán at the Museu Darder d'Història Natural (Banyoles, Girona), April 2019; Can Xerric (Serinyà, Girona); Llibreria 22 (Girona), May 2019; and at Llibreria Imatge (Barcelona), June 2019. (CD Edition).

Other unique works would be concert talks always related to music and science, such as:

«**La música de Selene**» (2015-2016)*, «**Solstitium**» (2018), «**Suite per a un planeta vermell**» (2019)*, «**Viatge a la Lluna**» (2020)* o «**Paisatges Sonors**» (2018). *With Rafael Balaguer.

Website: <http://www.xavierdepalau.net>



Sonification studio, Xavier de Palau

Rafael Balaguer.

Rafael Balaguer Rosa (Barcelona, 1971) is a prehistorian and astronomer. Especially interested in and committed to scientific dissemination, he focuses on the task of communicating astronomy and paleoanthropology, giving courses and conferences, in which audiovisual supports stand out, as well as conducting public astronomical observations, especially with Astrogirona, Astronomical Association of Girona, where he has been linked to its management since its origins in 1999 and of which he is president, and where he conducts studies on meteorology, solar activity, spectroscopy, and exoplanets. In this sense, he has promoted the construction and directs the two observatories that the Girona Astronomical Association put into service in 2011 in Llagostera (Girona).

His vitality and great interest in all aspects related to astronomy and paleoanthropology have led him to travel around the world bringing a transversal vision to astronomical discipline, combining it with anthropology and archaeology. He is currently conducting an international scope research, totally pioneering in the field of archaeoastronomy, which studies the relationship between the location and orientation of megalithic monuments with the geomagnetic field of the Earth.

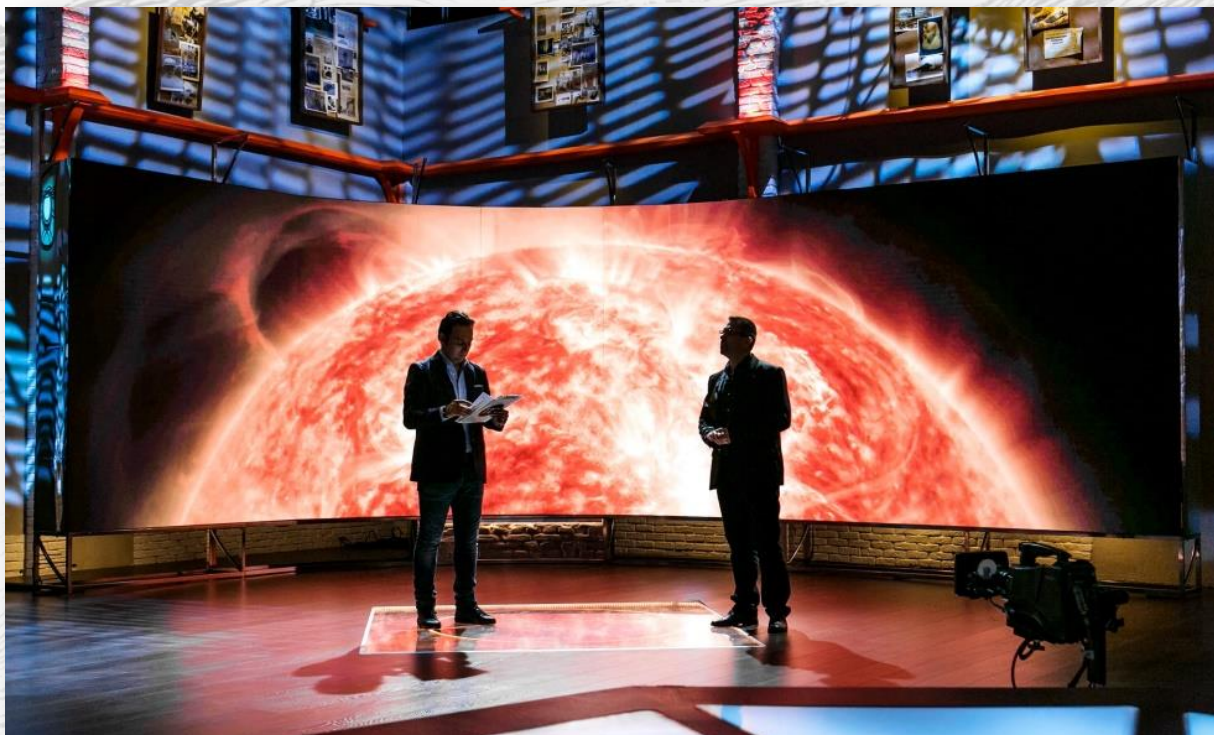
He also actively participates in the Spanish Research Network on Bolides and Meteorites, under the coordination of Dr. Josep Maria Trigo Rodríguez.

Along with him, and as a member of the International Meteorite Collectors Association, he participates in several field investigations in search of meteorites.

With extensive teaching experience and as a scientific communicator, [his works](#) have been published in prestigious journals such as "AstronomiA", "Tribuna de Astronomía y Universo" and "Nostra Nau", and have also been disseminated through media, written and audiovisual of all areas, local, regional, state, with which he regularly collaborates, as for example currently in the TV show "Cuarto Milenio", on Cuatro TV with Iker Jiménez, as a consultant and scientific collaborator; and also in the radio show "Madrid directo", on Onda Madrid, with Nieves Herrero, with a weekly section on astronomy and prehistory. He also collaborates with Radio Aragón, in the radio show "Abismo", with Nacho Navarro, and with the TV show "Destinos místicos", on the American TV channel Mega TV.



Geomagnetic studies. Left, Menhir de Champ-Dolent, Dol-de-Bretagne. Right, Stonehenge, Jessica Lleonart



On the set of the TV show "Cuarto Milenio", with Iker Jiménez, Annaís Pascual

Websites: www.telurium.net / www.delacuevaaluniverso.com

Thanks.

Rafael wants to thank Jessica Lleontart for her love and unconditional support in all his crazy adventures, and Xavier de Palau for his friendship, always inspiring and essential, without him this project would have been impossible. Rafael and Xavier thank Astrogirona and its observatory "Can Roig MPC C99" for their availability to use their facilities and instruments, Pere Guerra and the observatory "Albanyà MPC L17" for their collaboration in obtaining the spectrum of the dwarf planet Ceres. They also thank Matthias Ordu, Juanita Osorio Ruiz and Lynne Finnigan for their effort and dedication in their exhaustive review of the texts of "Music From Light".

4.- Tracklist from "Music From Light", sorted by increasing distance from the Sun.

Sun, 2:37

Solar Corona, 2:38

Mercury, 1:24

Venus, 2:39

Earth, 2:40

Voices of the Moon, 3:22



Moon Eclipse, 2:36

Mars, 1:20

Vesta, 2:26

Ceres, 1:27

Jupiter, 1:24

Saturn, 1:27

Uranus, 1:23

Neptune, 2:37

Pluto, 2:38

Lovejoy, 1:26 ⁽¹⁾

Wirtanen, 2:41 ⁽²⁾

Panstarrs, 2:41 ⁽³⁾

Neowise, 2:40 ⁽⁴⁾

Sirius, 1:43

Procyon, 1:41

Altair, 1:27

Vega, 1:27

Pollux, 0:57

Castor, 1:26

Aldebaran, 1:22

Hyadum II, 1:23

Hyadum I, 1:25

Gomeisa, 1:30

Mirach, 1:29

Bellatrix, 1:24

Mirzam, 1:51

Betelgeuse, 1:26

Dimmed Betelgeuse, 2:40

Rigel, 1:24

Mintaka, 1:32

Meissa, 1:26

Orion Nebula, 2:37

Deneb, 2:20

(1).- Comet C/2014 Q2 Lovejoy

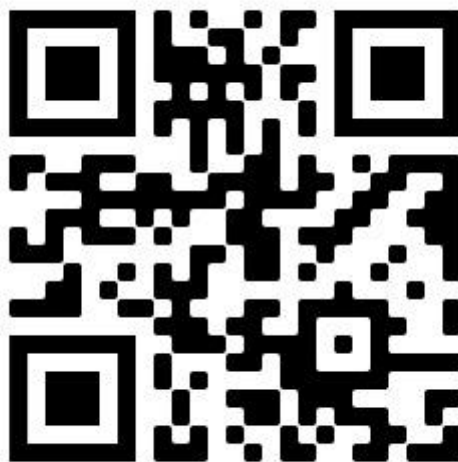
(2).- Comet 46P Wirtanen

(3).- Comet C/2017 T2 PANSTARRS

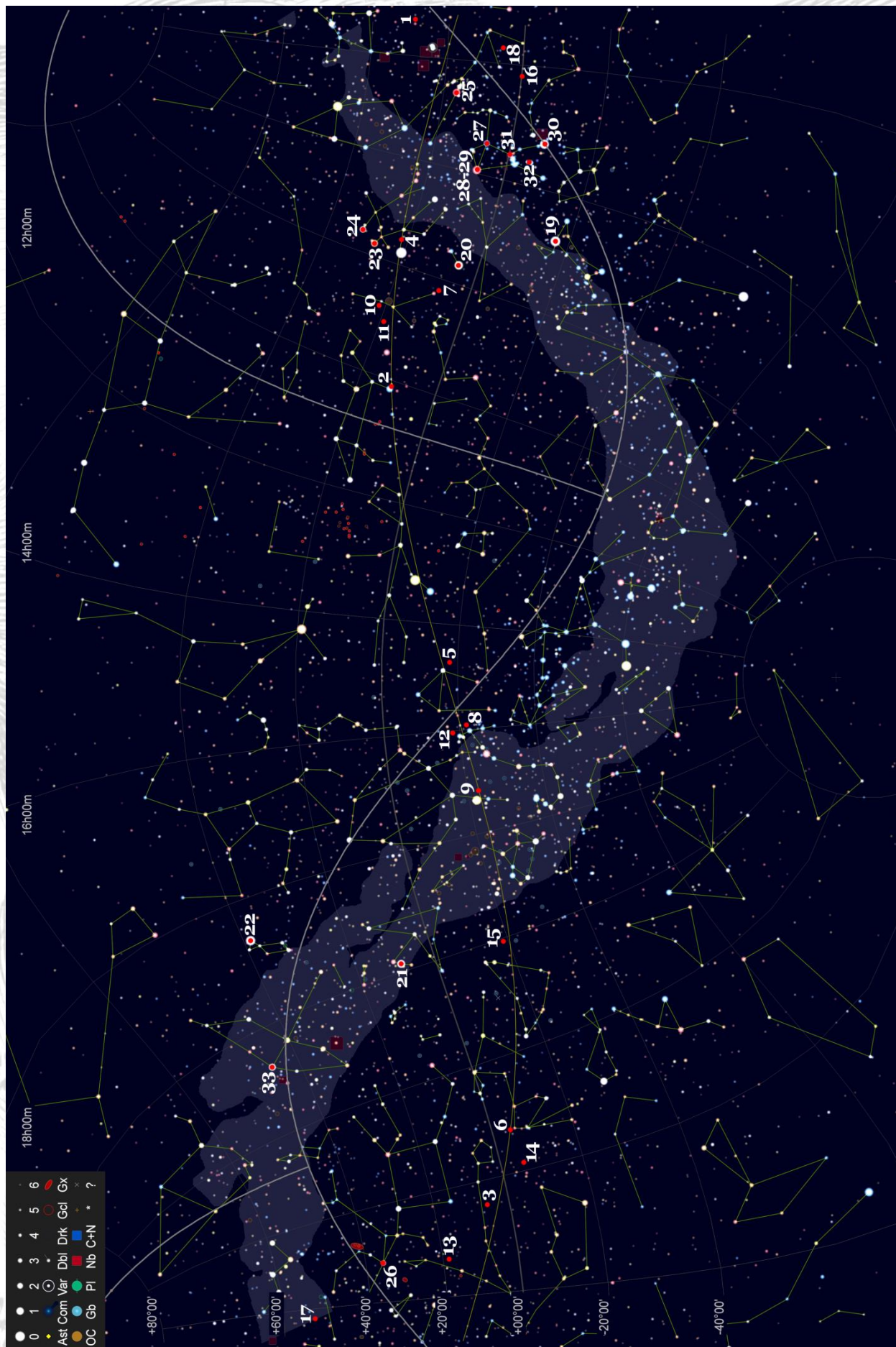
(4).- Comet C/2020 F3 NEOWISE



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Sky map showing the position of the sonified stars for "Music From Light", Rafael Balaguer

