Willem Boogman

Sternenrest

for electric guitar, percussion, ensemble, computer and sound projection
2007-2008

Commissioned by *November Music Festival 2008 & Spectra Ensemble*
with financial support from the *Netherlands Fund for Performing Arts+*

In memory of Karlheinz Stockhausen

The electronic music was realized at the *Institute of Sonology* in The Hague in cooperation with lecturer/composer Johan van Kreij and the students Billy Bultheel and Casper Schipper. I am very grateful to them and to Kees Tazelaar, director of the Institute.

The electronic music was especially designed to be projected by means of the Wave Field Synthesis loudspeakersystem as developed by *The Game of Life*. We are very greatful to the members of this foundation for the many opportunities they have offered us to work intensively with the system.

The concert version of *Sternenrest* was premiered on November 14, 2008 at Het Bossche Makershuis, Boschveld in 's-Hertogenbosch, during the November Music Festival by Olaf Tarenskeen - electric guitar, Arnold Marinissen - percussion, SPECTRA Ensemble (Jan Vercruysse - bass flute, Kris Deprey - bass clarinet, Frank Van Eycken - percussion, Pieter Jansen - violin, Bram Bossier - viola, Lieven Baert - violoncello) and Wouter Snoei - sound direction.

Duration: ca 47:57

STERNENREST
(the cycle)

Sternenrest is a cycle of three compositions that follow each other without a break. All of them can be performed independently, under different titles and/or in slightly different versions.

I
Seeds of Structure
for electric guitar, computer and Wave Field Synthesis
[ca 18 minutes]
dedicated to Olaf Tarenskeen

II
GLAS *(based on the star HD 129929)*
for glass percussion, computer and Wave Field Synthesis
[11:34]
dedicated to Conny Aerts

III
Liminale
for ensemble, computer and Wave Field Synthesis
[18:23]
dedicated to Filip Rathé

SCORING of the ensemble:

Bass Flute
Violin
Violoncello

Bass Clarinet
Viola
Percussion I
(one player)

Percussion II
(one player)

The ensemble is divided into two groups of three players each, plus one extra percussionist.
The ensemble is not to be conducted.
The part of percussionist II can be performed by the solo percussionist of GLAS.

All instruments sound as written

PERFORMANCE MATERIALS AVAILABLE

For the sound director: a complete score on A4 paper, landscape.

For the guitar player: part on B4 paper, landscape, with on one line the rhythm of the elecronic music.

For the glass percussionist: loose-leaf performance score on A3 paper, landscape.

For the seven ensemble players: parts on B4 paper, portrait.

CONTENTS

STERNENREST

(*Stars don't make music*)

The project, the music and the instruments

The project

It came as a great surprise to hear that stars produce 'music' – at any rate this is how the asteroseismologist Conny Aerts described the existence of acoustic vibrations in stars during her lecture entitled *Kosmische symfonieën* [Cosmic Symphonies] (Nijmegen 2005). In doing so, she perhaps unintentionally created a connection between the inaudible sounds of the stars, that only exist in scientific measurements and models, and our (musical) imagination.

It has become apparent that sound plays an important role not only in the life of stars, but also in the formation of structures in the universe. By analyzing these sounds it is possible to obtain knowledge about the internal structure of stars and the evolution of the universe in exactly the same way that sonologists are able to lay bare a tone's structure, which would otherwise remain concealed from us.
In *Sternenrest* an attempt has been made to integrate a number of scientific results from asteroseismology, cosmology and sonology into music and video. The varying scales of the structures here concerned are rendered audible, visible and recognizable by combining instrumental music with electronic music and video. The audience is surrounded by instrumentalists, 192 loudspeakers, and video screens.

The composer Willem Boogman developed the project in close collaboration with the philosopher Chris Bremmers, the video maker Mateusz Herczka, and with the scientist Conny Aerts, who answered all questions about 'her' star HD 129929 with great dedication, providing the measurement data and the required interpretation of it.

The subtitle *Stars don't make music* gives rise to the question in what sense do stars and the night sky possess an aesthetic dimension, and how can this be made accessible to us and be expressed in music and other art forms. From the very beginning Chris Bremmers embedded *Sternenrest* in a reflection on diverse aspects of the relationship between science and art and the relationship between science and the observation of stars in everyday life.

The various ways of discovering and observing stars and the night sky and their interrelationships make up the theme of this interdisciplinary project.

The music

GLAS (*based on the star HD 129929*) occupies a central position in *Sternenrest*. Its music is modeled on the measurement data and results of the research into the star HD 129929, as formulated by Conny Aerts in the scientific magazine *Science* (2003). The measurement data includes six star frequencies and details about the star's various rotation layers and rotation speeds. Thanks to the possibilities inherent in the Wave Field Synthesis loudspeaker system, the audience can imagine itself inside the star, from which position the sound waves and sound movements of the star can be followed. This movement deals with the star's development from her first light until the point that she explodes (supernova). The discovery in 2006 that acoustic sound plays a decisive role in a star's supernova phase also played a part in the music's development.

The preceding part, *Seeds of Structure*, can be regarded as a musical reverie at twilight, as the stars begin to appear in the night sky. But the surface of this piece also reflects the formation of the universe and the birth of a star, in which sound plays an important role, as hypotheses and recent discoveries in cosmology and astronomy have shown. Stars and galaxies emerge in an essentially empty universe on the edges of vastly inflated and frozen sound waves that were already present in the primeval soup just after the Big Bang. These sound waves were discovered as minuscule ripples in the otherwise smooth cosmic microwave background radiation. They act as the seeds of large-scale structures in the universe such as galaxies. In this part of *Sternenrest* small and large-scale structures form a close relationship with each other. The final result is, also in the music, the birth of a star.

The last part, entitled *Liminale*, starts just after the 'explosion' of the star, in which her core is 'kicked out' and her remnants gradually disperse throughout the universe. The core continues to exist as a pulsar, gets a little sister, whereby a double pulsar system is formed. The two pulsars spiral slowly towards each other, finally coalescing to form a black hole.
The music here is based on the data of the double pulsar system PSR J0737-3039. The ensemble is spatially positioned and plays chords which are constantly changing in color, in a cycle which represents the alternation of day and night. The composition ends with the break of day, as it were.

The instruments

The instrumental scoring changes three times in the course of the piece: from electric guitar to glass percussion to ensemble.
In the main the electric guitar is played with a small stone, making possible the production of extremely subtle tones in areas otherwise inaudible, beyond the normal range of the guitar. The percussion consists of twenty-two glass instruments including lampshades, vases, bowls, table tops etc. Having been sampled and analyzed, they form the basis for the electronic music.

The electronic music was developed at the *Institute of Sonology* in The Hague with the help of the lecturer/composer Johan van Kreij and the two students Billy Bultheel and Casper Schipper. They designed the software and realized the electronic sounds, which are projected by means of Wave Field Synthesis. This system, built by the Dutch foundation *The Game of Life*, consists of 192 loudspeakers and eight subwoofers and was presented in 2006. The system projects sound evenly throughout the listening space, and makes possible an exact positioning, and moving around, of sounds in relation to the listener.

SETUP
(concert version)

Audience
The audience is surrounded by the Wave Field Synthesis system (WFS):
192 loudspeakers, 8 subwoofers.
The audience is seated with their backs to the lines of speakers. A maximum of 88 seats is possible, depending on the width of the chairs.
The first row of chairs is placed roughly two chairs' width away from the speakers.

Space needed
The loudspeaker setup occupies an area of 10m x 10m.
An area of 18m x 18m is the minimum required for the setup of the instruments.
That is to say 4m extra on each side of the WFS.
The larger the hall the better, and a hall with generous acoustics is preferable to one with dry acoustics.

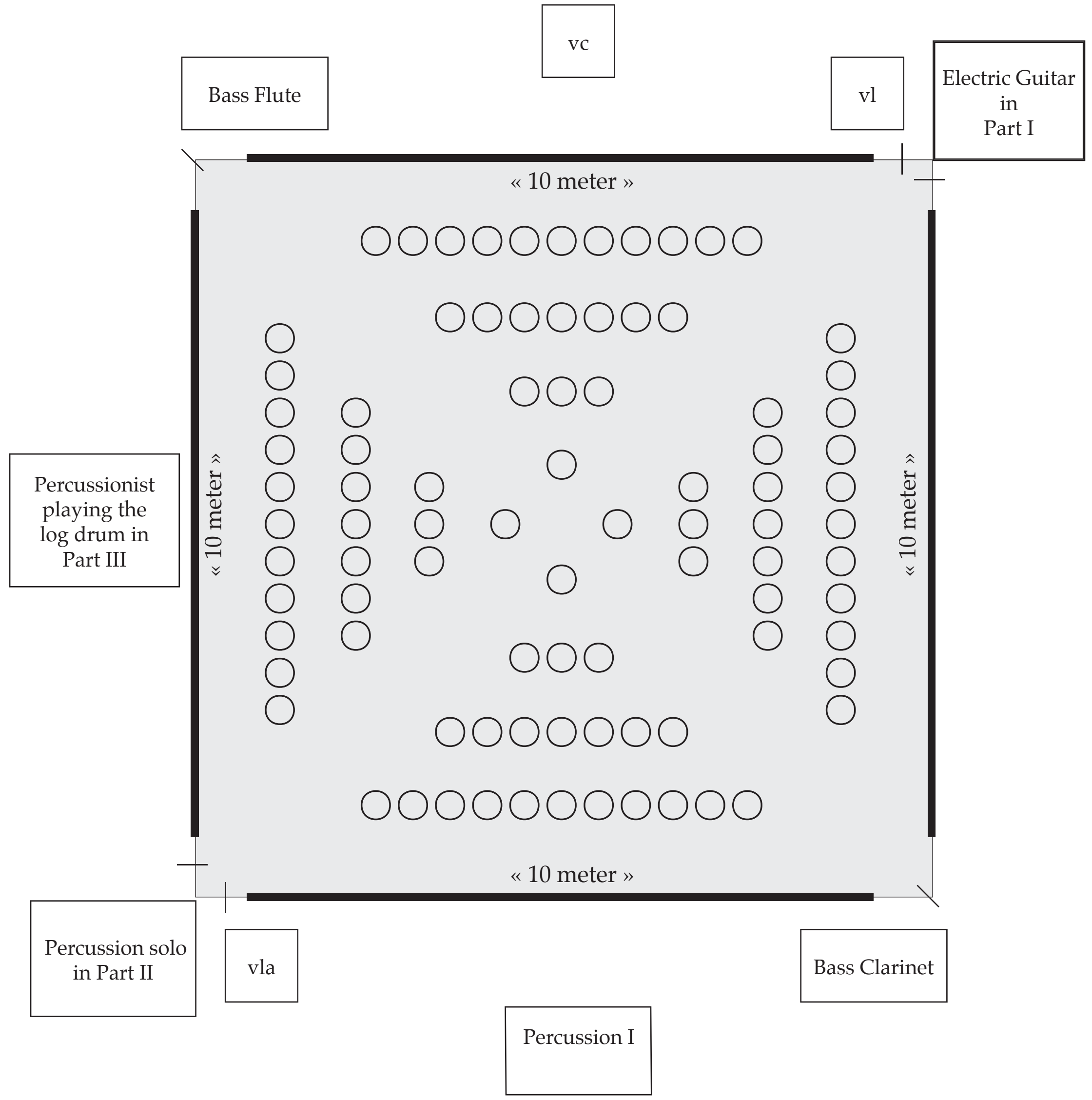
Wave Field Synthesis
For an unimpeded projection of the sound above the audience's heads, the center of the loudspeakers should be adjusted to a height of 1.4m above the floor.

Sound direction
The sound director needs a small table to put his laptop on, and a music stand, both placed somewhere in the middle of the audience.

Lighting
The hall should never be dark [concerts without video]: the audience (and the musicians) should always be able to orientate themselves in the hall.
The guitarist and solo percussionist are spotlighted when they play.
The musicians of the ensemble are spotlighted ad lib.
Music stand lights are necessary.

Click Track
In theory all the musicians could play along with the electronic music without a click track**,** the guitarist taking his cues from the entrances of the electronic 'stars', the glass percussionist from the pulses of 'Rf5' and the ensemble from 'Pulsar B' at first and later on from the pulses played by percussionist II.

In practice a click track for each musician can be used where it is needed.



The guitarist plays on a platform of 2m x 2.5m

Where circumstances allow, *Liminale* should start with the bass flutist, violinist, bass clarinetist and viola player entering the hall and slowly walking to their seats during approx. 3 minutes while playing. See score p. 20

SYMBOLS AND ABBREVIATONS

Long vertical arrows clarify the musical structure and must receive extra attention.

Gradual transition

Continue / maintain same situation

('Tenuto') The sound ceases *at* the rest.

Ceasura within the notated duration: do not interrupt the beat of the music.

Short interruption of the music (a 'frozen' beat)

Longer interruption of the music ('freeze')

Niente

Overtones as a result of striking a muted string or instrument

Notes to be dubbed into a delay / loop.
(only in *Seeds of Structure*)

Notes with added pitches by pitch shifting.
(only in *Seeds of Structure*)

n Normal (after sul ponticello [*sp*] or sul tasto [*st*])
(only in *Liminale*)

Encircled dynamics (only in *Liminale*):
Dynamic level as part of sound rotation

NOTES FOR SEEDS OF STRUCTURE

(for an elaborate explanation see the preface to the guitar part)

INSTRUMENT

Seeds of Structure was written for a solid body guitar or a semi-hollow body electric guitar, type Gretsch. Olaf Tarenskeen played the music very successfully on a Fender Stratocaster, the bridge pickup being selected during the tapping of the small stone (see: Effects), and the neck pickup during the 'cantabile' part for a full, warm tone.
The third string should be wound.
Amplifier: the Fender Stratocaster was used in combination with a **clean** sounding Fender Deluxe Reverb. The sound of this amp can be considered as a reference sound: the composer prefers the warm sound of a tube amp. The music needs to be projected softly but with a 'wide' (stereo-) sound that reveals a lot of subtle details. Use an amp with large power (watts) to give the delays a clean sound.

Input chain: guitar input – – DD-6 – – CE-5 – – ME-50 – – output
(Olaf Tarenskeen)

EFFECTS

Except for the small stone, effects do not appear until the last two pages of the score. No distortion of any kind should be used during this piece.

Chorus should always be very slow; the same settings are used for each effect group. It creates 'waves' on tones that are dubbed into a delay. These wave motions should be allowed to run their full course, not being cut off by the delay.

Delay should be able to repeat the sound endlessly. It operates with a maximum of feedback: the sound should maintain its intensity, not getting softer!

Pitch shifter should be able to add two pitches to each source tone. However, see the preface to the guitar part for alternatives.

SMALL STONE

For most of the time the electric guitar is played with a small stone held in the right hand. Strings are scraped or tapped by this stone, or it executes glissandi. The part for the RH, employing the small stone, is written on the upper staff, while the LH actions are notated on the lower staff.

Left-hand actions:

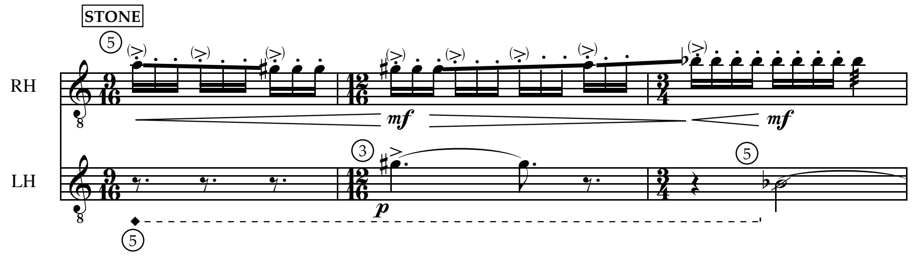
Left-hand finger battuto, sostenuto

Stop the indicated notes silently. The stopped note will resonate due to RH's actions involving the string in question.

Damp the 'fundamental' tone by keeping the string slightly depressed with one finger as if playing a harmonic. No resonance tones will sound. It does not make any difference where on the string you perform this effect.

open Open string. The open string will resonate due to RH's actions. Also notated with the symbol: **o** on notehead side.

Example, score p. 6 bar 150-152
Staccato notes in the RH indicate the tapping with the small stone on the string. The tremolo on the last note indicates scraping the string. Note the two simultaneous actions of the LH in the second bar.

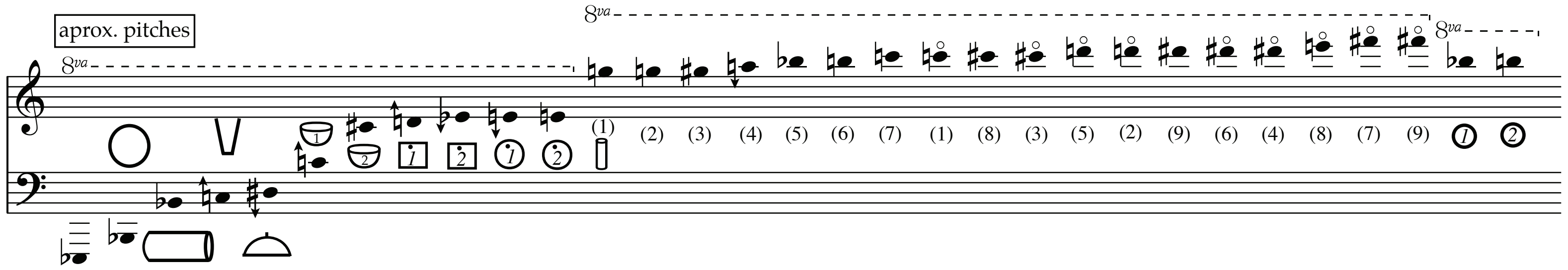


The dynamics which apply to the part of the small stone are to be executed by the intensity of the tapping / scraping, not by regulating the volume of the electric guitar.

NOTES FOR **GLAS** (based on the star HD 129929)

All 22 instruments are made of glass. The sound of the original instruments has been used as material for the electronic music. As the correspondence between the electronic and the acoustic music is supposed to be audible, these instruments will be hard to replace and/or reproduce.

All 31 pitches



SETUP

left side view:

large vase/bowls
large round plate

very large round plate

right side view:

small square plates

small round plates

lampshade

large vase

two bowls

nine tubes

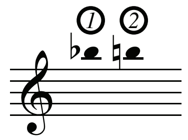
ribbled plates

large tube

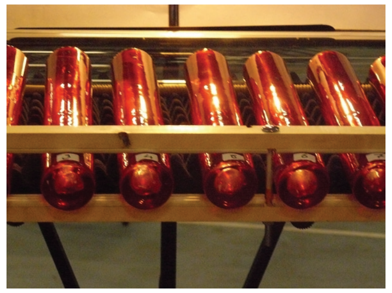
tub of water

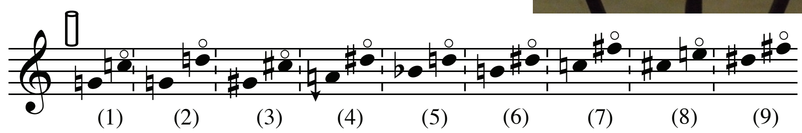
INSTRUMENTS

2 Small round, ribbled plates
sound an octave higher than written
(also to be played with two tuning keys)

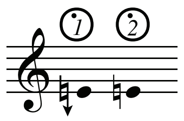


9 Tubes
sound two octaves higher than written
Each of them has two tones: the fundamental and a clear overtone, indicated as such.

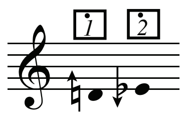


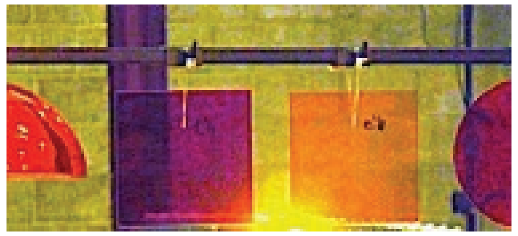


2 Small round plates, suspended
sound an octave higher than written

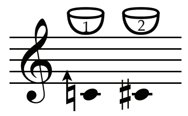


2 Small square plates, suspended
sound an octave higher than written

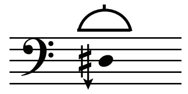


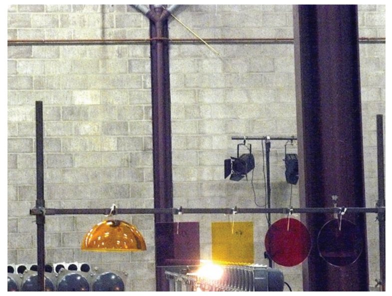


2 Bowls
sound an octave higher than written

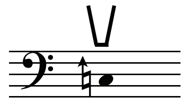


Lampshade, suspended
sounds an octave higher than written

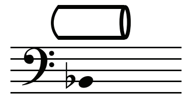




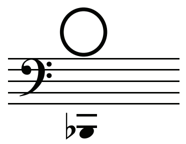
Large vase
sounds an octave higher than written



Large tube
sounds an octave higher than written

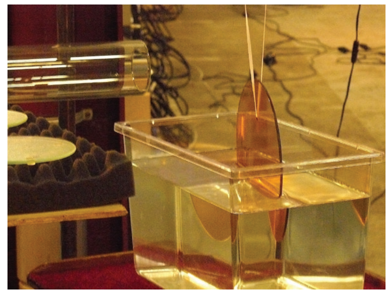


Large round plate
sounds an octave higher than written



Very large round plate
This instrument should have the lowest available pitch.

Tub of water
Plate 2 of the small round plates is struck, then lowered into a tub of water to bend the pitch.



AMPLIFICATION
(as part of the percussion setup)

Amplification is required for:
Large Tube:
a microphone is placed in one end of the tube and at the opposite end is struck with the outstretched palm of the hand.

Optional:
Tub of Water:
one microphone for the amplification of the "waterplate" and the drops of water.

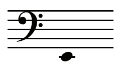
NOTES FOR LIMINALE

The musicians take their cues from the pulse of 'Pulsar B' and, after 13:25, from the pulse played by the percussionist II. These pulses are indicated in the parts.

PERCUSSION INSTRUMENTS

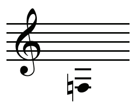
PERCUSSION I

Wind Gong (in E)
suspended and to be played seated
in order to damp the instrument between the player's knees.



Vibraphone

Log Drum (in F)
or Slit Drum



Glass Chimes

PERCUSSION II

Log Drum (in F)
or Slit Drum

ELECTRONIC MUSIC

OVERVIEW

The electronic music exists as a Wave Field Synthesis application and comes with two files: the first file is to be played in Part I (total duration: 0 - 3:42.8), the second file is to be played throughout Parts II and III (total duration: 0 - 29:57.7).

Part I, Seeds of Structure

Transposed Glass_chords [3:42.86]
Stars begin to appear in the night sky.

Part II, GLAS (based on the star HD 129929)

1a. Glass_Chord in circles [0 - 16.286]
The star's first light. It moves from the core to the outer layers. While moving it passes the different surfaces of noise.
1b. Circles of noise [0 - 16.286]
Exposition of the noise-surfaces and where they are situated in the star.

2. Core [16.286 - 10:04.286]
The core starts to function and during the star's life it develops from 'water' to 'glass', to 'rubbed glass', to 'stones', to 'metal'. At this stage the core will collapse. This happens at 10:04 (supernova).

3a. Rf5-mode [16.286 - 10:04.286]
Rf5 is the 5th frequency of the star HD 129929.
3b. Rf5-mode [10:04.286 - 11:28.286]
In the supernova phase, which starts at 10:04 minutes, Rf5 behaves differently.

4a. Noise surfaces P-modes [16.286 - 10:04.286]
The three P -modes are the 2nd, 4th and 6th frequency of the star HD 129929.
4b. Noise surfaces G-modes [16.286 - 10:04.286]
The two G -modes are the 1st and 3rd frequency of the star HD 129929 .

5a. Noise surfaces Pf2- and Pf6-modes [10:04.286 - 11:28.286]
5b. Noise surfaces G-modes [10:04.286 - 11:28.286]
5c. Noise surface Pf4-mode [10:04.286 - 11:28.286]
In the supernova phase, which starts at 10:04 minutes, the frequencies behave differently.

6a. Traveling Waves P- and G-modes [16.286 - 10:04.286]
Six sound waves travel in specific cavities inside the star.
6b. Traveling Waves P- and G-modes [10:04.286 - 11:28.286]
In the supernova phase the traveling waves behave differently.

7a. Core_pulse [10:04.286 - 11:28.286]
In the supernova phase the core has collapsed and the inner core starts to oscillate violently. This oscillation generates sound waves: Core_Traveling Waves.

7b. Core_Traveling Waves [10:04.286 - 11:28.286]
Core_Traveling Waves *move from the core to the outer layers and back to the core. Their frequency increases to about 300 Hz. These sound waves actually cause the star to explode.*

Transition to Liminale

Silence [11:28.3 - 11:34.6]
Time needed for WFS to start up the files for Part III.

Part III, Liminale [11:34.6 - 29:57.75]

1. Shattered Glass I [11:34.6 - 12:34.1]
Cloud of glass splinters. Its density rapidly decreases to zero.

2. Core_Pulse kicked out [during 6.34]
After the core-pulse has reached its fastest pulsation (300 bpm) it leaves its place inside the core and spirals towards location 0.9 at 180°. Its speed slows down to 75.71 bpm. It continues its life as Pulsar B.

3. Pulsar B [11:41.79 - 24:59.8]

4. Shattered_Glass II [12:34.1 - c 29:39]
Cloud of glass splinters. Its density decreases to zero, covering ca 18 minutes. In this music, which was inspired by a picture of the shattered fragments of Cassiopeia A, the glass cloud moves outwards in irregular circles. At times loose fragments appear at closer distances.

5. Remnants A and B [12:40.4 - 28:37]
Different combinations of glass tones, spiraling outwards and inwards.

6. Pulsar A [12:34.1 - 24:59.8]

7. Black_Hole [24:59.8 - 29:39.9]
7a. Wind I and Wind II
7b. Crowd
Black holes produce powerful rotating winds, which surround the black hole. 'Crowd' is a transformed wind that sounds like a bustling crowd.

8. Coda_Chords [28:37 - 29:39.9]
All six glass chords are heard in succession, and gradually revert to the original sound from which they were sampled.

Frequencies
From analysis of the light variations of the star HD 129929 six pulsation frequencies and their oscillation modes were detected. These oscillations were identified to be the radial (*l* = 0) fundamental Rf5, the dipole (*l* = 1) P-mode triplet and two consecutive components of the quadrupole (*l* = 2) G-mode quintuplet.

Frequency $c\ d^{-1}$	Transposed (22 octaves)	Splittings	Frequency splittings $c\ d^{-1}$	Nodes	Modes
Gf3 = 6.449590	313.09654 Hz	parts of a quintuplet	f1-f3 = 0.012109	$l = 2$, $m = ?$, g_1	
Gf1 = 6.461699	313.68438 Hz			$l = 2$, $m = ?$, g_1	
Rf5 = 6.590940	319.9584 Hz	fundamental		$l = 0$, $m = 0$, p_1	radial mode
Pf6 = 6.966172	338.17411 Hz	triplet (overtones)	f2-f4 = 0.012126 f2-f6 = 0.012133	$l = 1$, $m = -1$, p_1	prograde mode
Pf2 = 6.978305	338.76311 Hz			$l = 1$, $m = 0$, p_1	
Pf4 = 6.990431	339.35177 Hz			$l = 1$, $m = +1$, p_1	retrograde mode

Table 1

From this data the **beat periods** of the frequencies and the **rotation velocity** of the star were determined.
For the beat periods see: **noise-surfaces** on the next page.

As well as one isolated frequency, Rf5, the table shows two multituplets. Multituplets have equidistant frequencies due to rotational splitting of the main frequency. Main frequencies have been written bold in the table above. The other frequencies are called 'split modes'.

Rotational periods for all layers were derived from this splitting. The star exhibits non-rigid rotation with different velocities for different layers. The star rotates faster near the core than in the outer envelope. See: **rotation**

Rotation
The star's rotational period averaged over all layers is ca 83 days.
The rotational period of the star's surface is 140.21 days.
The rotational period of the core overshooting region at 0.15 x the radius is 43.6 days.
The rotational period of the core is 38.9 days.

It is the the noise-surfaces that rotate in the music. See: **noise-surfaces** on the next page.

See for the four rotation layers the adjoining diagram of spatialization.

Modes	Shell	Star rotation	Transposition	Velocity	Duration
Pf2	0.6 - 1	140.21 $c\ d^{-1}$	2^{22}	2.857^s = 21 BPM	3:02.857
Pf4/Pf6 split modes	0.4 - 0.6	82.58 $c\ d^{-1}$	2^{22}	1.7143^s = 35 BPM	1:49.714
Gf1	0.15 - 0.4	43.6 $c\ d^{-1}$	2^{22}	0.9^s = 66.6 BPM	57.6
Gf3 split mode	0.4 - 0.6	82.58 $c\ d^{-1}$	2^{22}	1.7143^s = 35 BPM	1:49.714
Core	0 - 0.1	38.9 $c\ d^{-1}$	2^{22}	0.8^s = 75 BPM	51.2
Rf5				0.79^s = 75.71 BPM	1:41.44

Table 2

Pf4 travels against the direction of rotation.

Rf5 rotates discontinuously as an exception. Rf5 jumps 45° counterclockwise from every ending of the previous sound wave to the point of a new entry. Its rotation velocity equals its period.

Resonance frequencies
One of the most intriguing facts about the star HD 129929 is that she can sustain her 'tones'. This is because certain layers of the star act as resonance cavities that determine all the sound's characteristics by reflection. See: **Traveling waves**.
We molded these resonance spectra by adding tones of a five-voiced **glass chord** and their spectra to each star frequency. These glass tones were derived from the spectral analysis of glass objects, which are played by the percussionist.

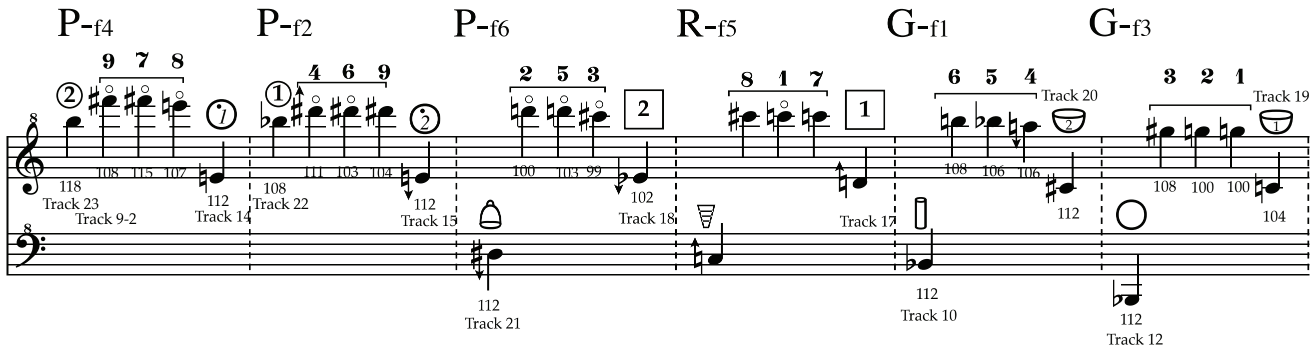


Fig. 1

Spatialization
The electronic music has been designed for exact spatial projection by Wave Field Synthesis and was plotted on this chart, see figure.
The square in the middle is the setup of the loudspeaker system: 10m x 10m, diagonal: 14.142m. This diagonal is equated with the circle located at 0.15 x the radius of the star. From this all the distances between the star's shells are derived.

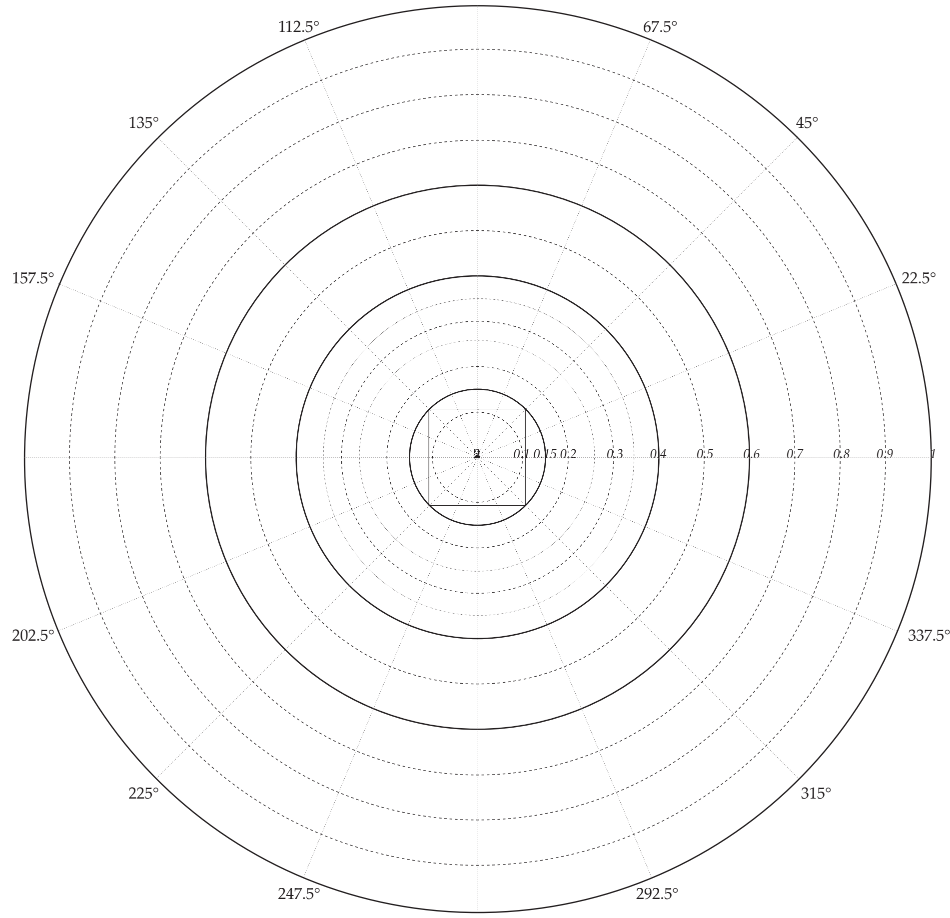


Fig. 2

Distances expressed in ... x the radius

0.1 = 4.714 m	0.5 = 23.5 m
0.15 = 7.05 m	0.6 = 28.3 m
0.2 = 9.45 m	0.7 = 33 m
0.25 = 11.75 m	0.8 = 37.7 m
0.3 = 14.15 m	0.9 = 42.5 m
0.35 = 16.5 m	1 = 47 m ('surface of the star')
0.4 = 18.85 m	

Inflation
During her lifetime the star expands. From 5:52 to 8:40 of Part II all the distances are gradually stretched out to twice the distance.
Because of this the traveling waves cover longer distances in the same time, with increasing Doppler effect.

Noise-surfaces

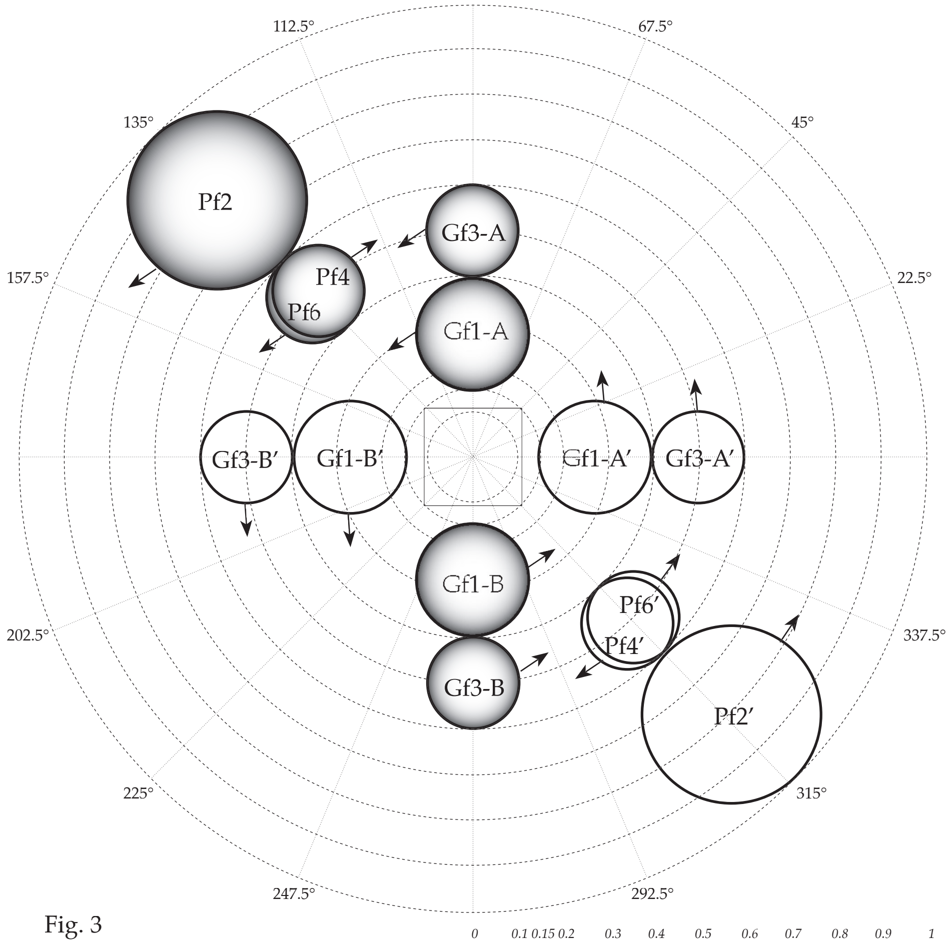


Fig. 3

2 dimensional pattern of the 'spherical harmonics' at the surface of the star.
Note the rotation directions.

What we have called **noise-surfaces** are a representation of the star's nodal surfaces.
When the darker regions are 'on' the transparent regions are 'off', and vice versa, with a silence (a 'node') at the transitional instant. The alternations occur in the tempo of the **beat periods** of the modes.
The beat period connected to Gf1 and Rf5 is 8 days. Transposed up 22 octaves results in Gf1 : Rf5, 52 : 53 beats.
The beat period connected to Gf1 and Pf2 is 2 days. After transposition: Pf2 : Gf1, 14 : 13 beats.
The beat periods last 3 sec for P-modes, 3.17 sec for the Rf5-mode and 3.23 sec for G-modes. All numbers are rounded off.

At sync points the waves cancel each other out.

Note that the P-mode surfaces oscillate *in two* (dipole indicated as P, P'), the G-mode surfaces *in four sections* (quadrupole indicated as G-A, G-A'; G-B, G-B').

At the beginning of supernova (10:04 minutes) the surfaces collapse onto the core, except Pf4.

Radial mode Rf5

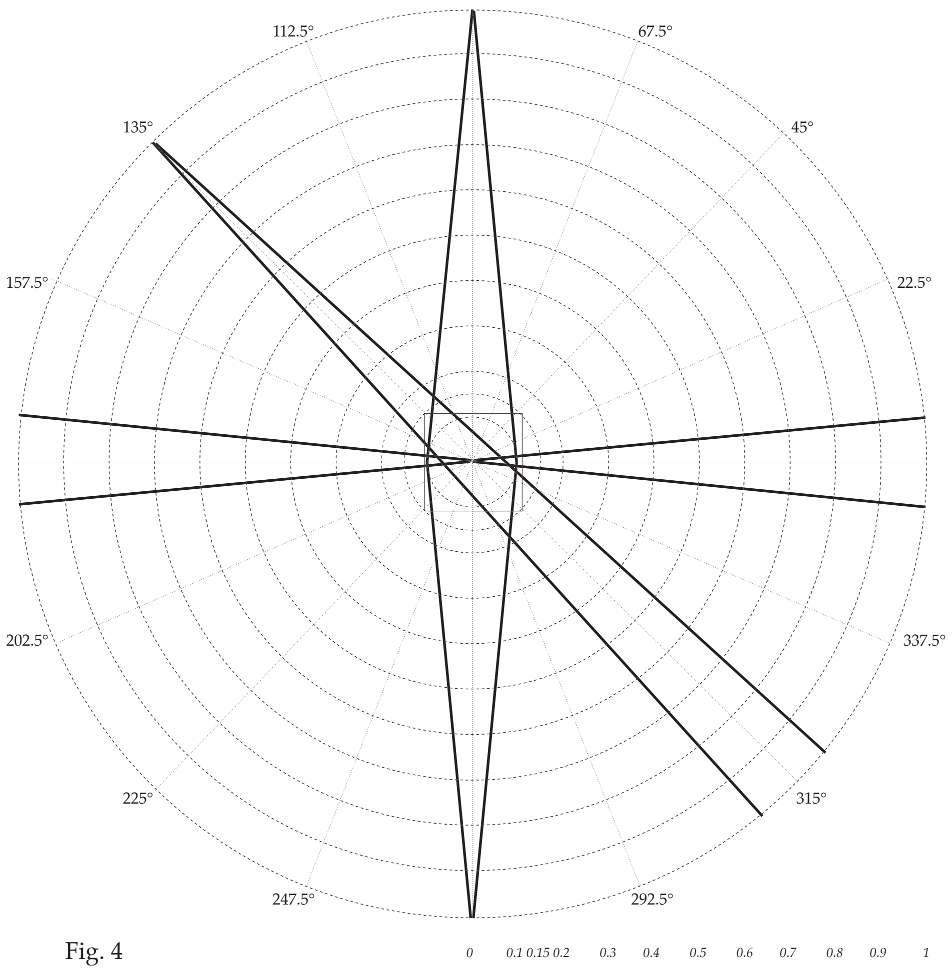


Fig. 4

The **radial mode** Rf5 is treated separately as a kind of traveling wave through the core of the star and as a noise-surface with changing densities, dimensions and rotation.

Considered as a noise-surface the Rf5 mode has its beat periods related to the other surfaces, P and G.

A perceivable beat has been added to Rf5 in the tempo of its frequency: 75.71 BPM. This metronome marking enables the percussionist to play along with the electronic music.

Rf5 sounds in noise, at times mixed with glass. Rf5 has four shapes:
<>, ><, < and > . These figures indicate the fluctuations of density and width. The envelope <> has been added only where glass tones appear. It never changes its shape.
Periods of Rf5 are 3.17, 6.34 and 12.68 sec.

After 10:04 minutes (supernova) Rf5 behaves differently. Now it is split up into two movements that start from the core (0) and travel simultaneously in opposite directions, towards a variable turning point. During supernova Rf5 covers increasingly long distances: from 0 - 0.15 to 0 - 0.7. Gradually it is filled with glass.

Traveling waves
Traveling waves are sound waves that are transmitted through the star. Their paths start from the surface, move towards the centre and slowly curve around, so that they miss the centre of the star. The point of closest approach is called the *turning point* of the mode. After the turning point the waves move out again until they reach the surface. At the surface they are reflected and they go back in again.
The deeper the waves penetrate the star, the faster they move, and their speed decreases after the turning point has been reached. This acceleration and deceleration was originally built into the composition, but this caused 'un-natural' Doppler effects when played by WFS.
The P-modes generally attain a large amplitude in the outer layers of the star while the G-modes have a large amplitude in the deep layers. According to the known 'core overshooting location', no G-mode penetrates deeper than 0.15 x the radius.

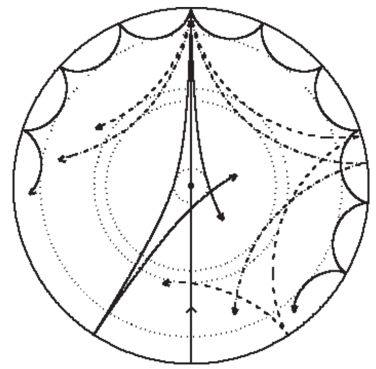


Fig.5 This diagram shows the cross section of a star with the paths of some traveling waves. The dotted circles represent the turning points. Note the radial wave going through the centre. Figure courtesy of Jørgen Christensen-Dalsgaard

A duration is assigned to each turning point. A traveling wave P, with its turning point at 0.4 x the radius, moves from surface to surface in 10.04 sec.

G-modes	Turning point	Duration
	0.15	15.48
	0.2	14.16
	0.25	12.95
	0.3	11.88
	0.35	10.9

P-modes	Turning point	Duration
	0.4	10.04
	0.5	9.39
	0.6	8.79
	0.7	8.22
	0.8	7.71
	0.9	7.23

The average speed of the traveling waves is 75 BPM.

Traveling waves are trapped in their resonance cavities. To realize resonance we mixed the star's frequencies with glass spectra. They were derived from the tones, both fundamental and overtones, of the glass percussion instruments. See: Resonance frequencies, fig. 1.

After 10:04 minutes the traveling waves propagate between the boundaries of the shells or move across the shells, in opposite directions. Only Pf4 maintains its position.

Supernova phase #4 of the noise-surfaces

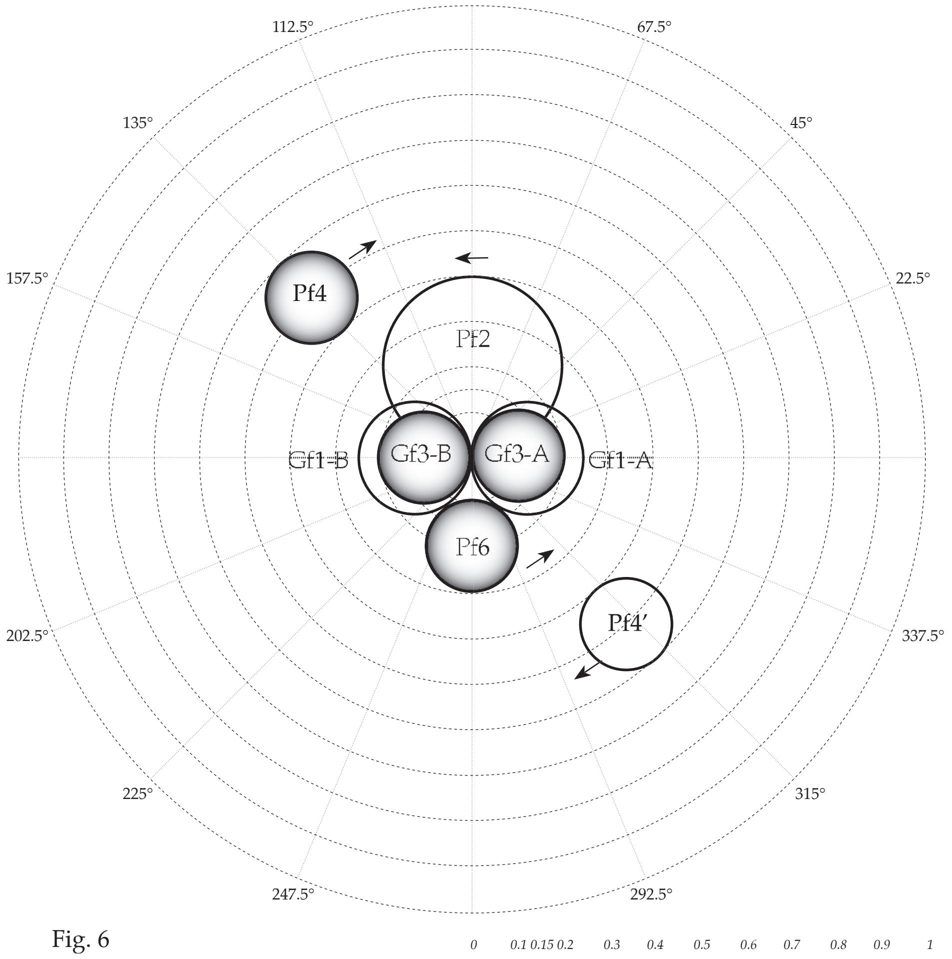


Fig. 6

The supernova phase in reality lasts less than a second, in *Sternenrest*, however, its evolution is followed during 84 sec.
At 10:40 in the score, the noise-surfaces, except Pf4, collapse onto the core. During 84 sec they slowly move outwards again, like a blast in slow motion, while gradually being filled up with glass.

As figures 7 and 8 show, the entropic outflow of 'surfaces' [flow fields] changes sides around the core. In fact these processes are described as being oscillations in the dipole and quadrupole mode. The explosion starts in a dipole mode and becomes a quadrupole mode. We have reproduced this in the electronic music. The surfaces evolve in 7 steps from oscillating *in one* to *in four*. Figure 6 shows step #4 where the G-modes oscillate *in four* and the P-modes still *in two*.

Rotation velocities have become much faster and more irregular. Pf4 in 70 BPM. Pf2 and Pf6 in 66.6 BPM and the G-modes in 75 BPM.

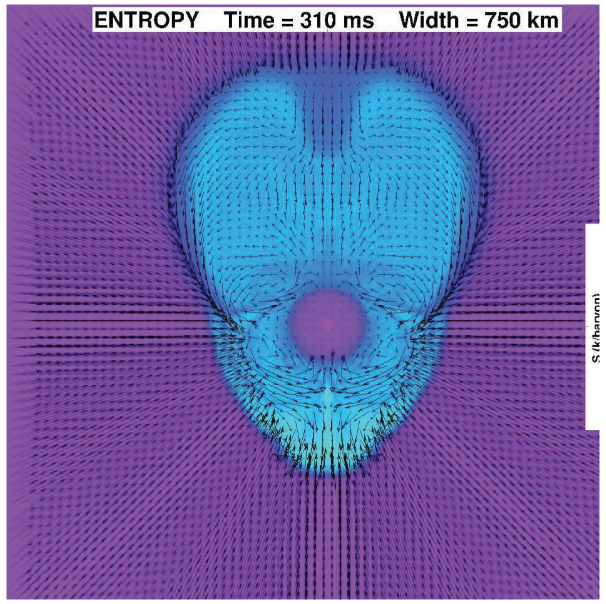


Fig. 7

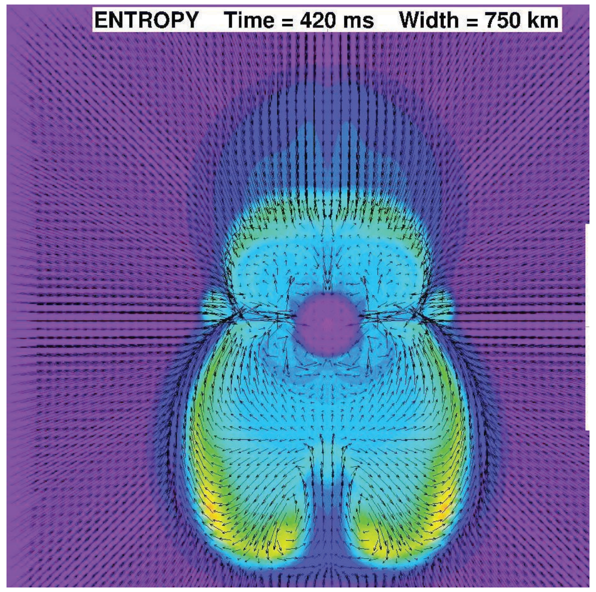


Fig. 8

Figures courtesy of Adam Burrows

Core_Traveling Waves #2, during supernova

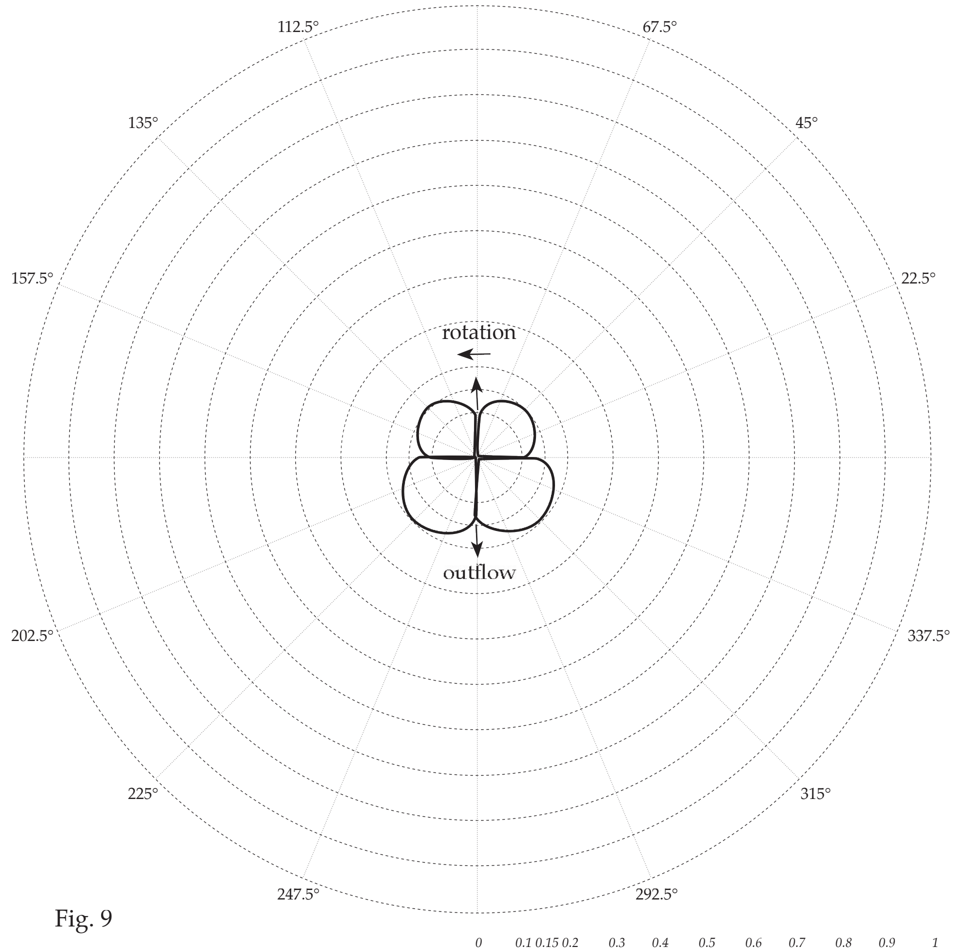


Fig. 9

Acoustic waves, Core_Traveling Waves, are transmitted asymmetrically outwards and backwards to the core. During supernova their frequency increases to about 300 Hz.
At first the waves flow in a dipole, later, as the figure shows, in a quadrupole manner. Note that the noise-surfaces act in the same way during supernova.

Finally the Core_Traveling Waves rip through the outer mantle of the star, that is to say, through the surfaces by now filled with glass, causing the glass to be shattered.

Core_pulse Oscillations
A pulse jumps back and forth, and in all directions, covering larger and larger distances from 0 to 0.15 x the radius. The velocity increases gradually from 75 BPM [0.8"] to 300 BPM.

Finally the core (the purple dot in figure 8) is kicked out. The core races as a neutron star (pulsar) into space, leaving behind asymmetric gas clouds: musically these are represented by clouds of shattered glass.
The core continues its life as Pulsar B.

Pulsar A & B

The music of Pulsar A & B is based on PSR J0737-3039, a binary pulsar system discovered in 2003, the first known double pulsar. The pulsars wobble, while orbiting each other, see fig. 10.

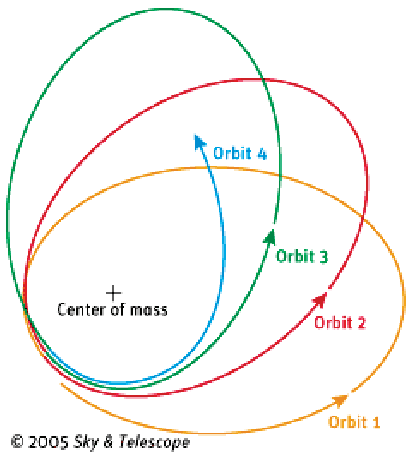


Fig. 10 The pulsars' elliptical orbit changes orientation.

Gradually the pulsars move closer together - spiraling inwards, their orbital motion become faster and faster and the orbits become shorter. Their pulsational energy decreases. The two pulsars finally coalesce into a black hole (fig. 11).

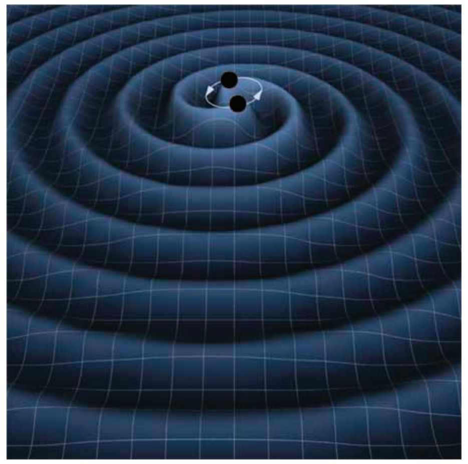


Fig. 11 Two objects spiraling inwards, producing ripples in the fabric of space-time. These gravitational waves are made audible in the music played by the ensemble: the time intervals between the chords expand and contract and in the end become somewhat smaller overall.
Figure courtesy of K. Thorne (Caltech), T. Carnahan (NASA GSFC)

Pulsar A has an eclipse between 80° and 110°. This eclipse is asymmetric, decreasing more slowly on ingress than it increases on egress.
Pulsar B has its stronger pulses at 210°, 280°, 30° and 60°. For the rest of the time the dynamic is generally softer and fluctuates randomly.

Pulsar A has a pulse period of 22.699 ms [2608.7 BPM]. In the music it slows down gradually to 81.5 BPM. From 24:49 it accelerates, finally reaching 84 BPM, which is the same speed as Pulsar B.

Pulsar B has a pulse period of 2773.5 ms [21.66 BPM] In the music this is rounded down to 21 BPM and transposed to 42 or 84 BPM.

In reality the orbit's duration is $2^{h}45^{min}$. Transposed 6 octaves: 137.8 sec and rounded down for the music to 137.14 sec.
Pulsar B starts at 0.9, 180° and Pulsar A, somewhat later, at 0.9, 360°.
Gradually the orbit's durations decrease and after 29 orbits the two pulsars finally coalesce at 0.4, 135°. Here the black hole comes into existence. In the score: 24:59.

Black Hole

Black holes produce powerful rotating winds, which surround the black hole. They act as accretion disks, causing remnants that come too close to be swallowed.
This idea has been developed in the music.
The radius of the 'accretion disk' is ca 9.35m. In normal conditions the rotation speed of the electronic winds is 1.43 sec.
The remnants spiral into the black hole in ca 3.2 sec, accelerating to ca 3000 Hz. As the climax is reached, a new remnant chord appears that is slowed down in ca 3.2 sec, after which it spirals outwards. (See: Remnants.)

The black hole starts at 0.4, 135° and from there it travels in stages to the location at 255° and finally to 15° where it dies out, due to the appearance of 'daylight'.

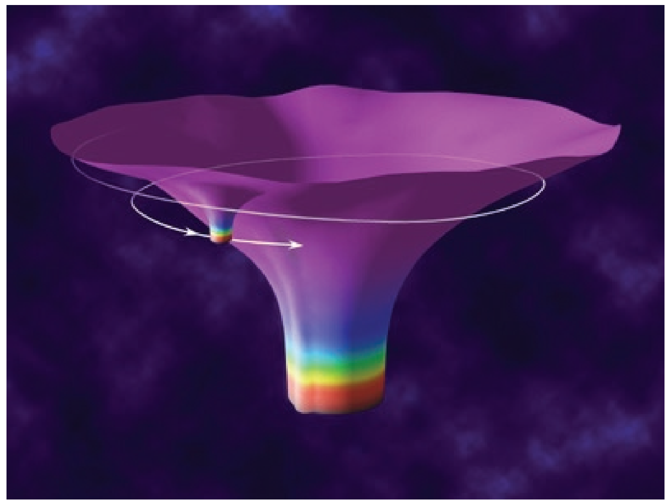


Fig. 12 An object spirals into a black hole.
Courtesy of the California Institute of Technology

Remnants
A, A' -- ●
B, B' -- ○

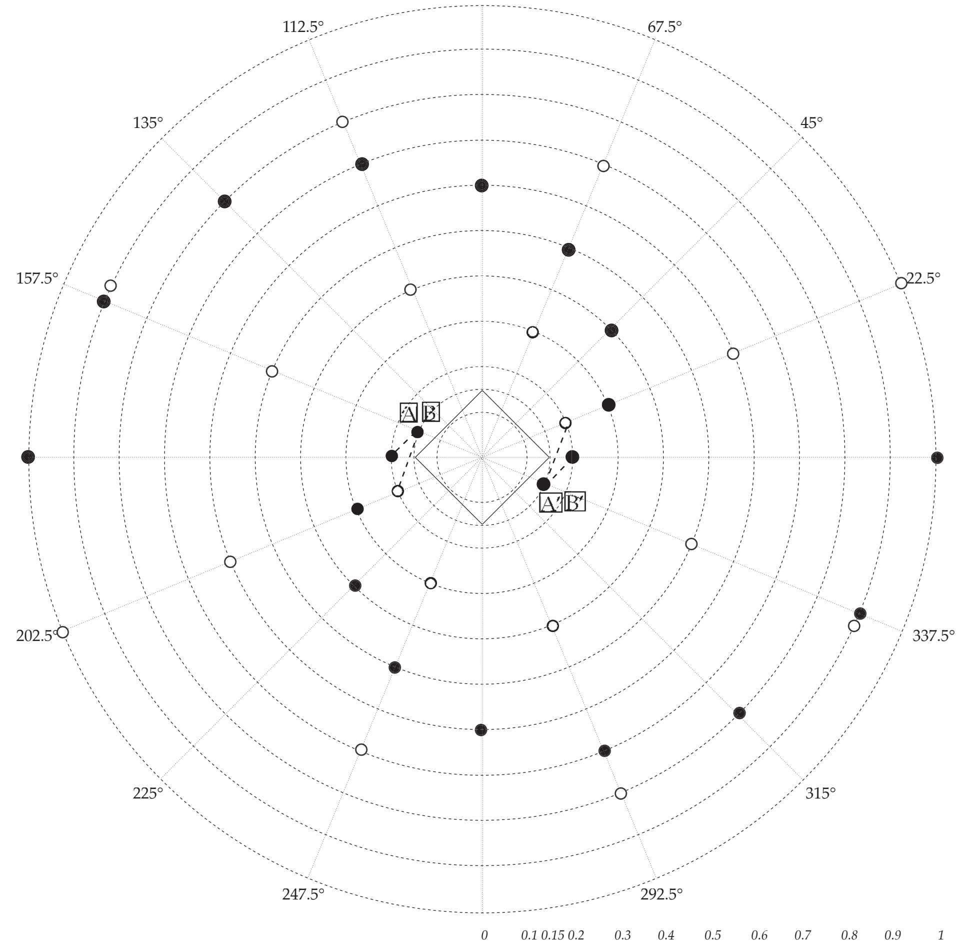


Fig. 13

Remnants consist of different combinations of the 30 tones of the glass chords. See fig. 1.
Their duration is linked to spatial position: the further away, the longer the tones sound.
At first the remnants A and A' move outwards in spirals and in opposite directions. Each successive entry jumps 90° clockwise.
After 21:34.2 minutes remnants B and B' join the A-remnants. B-remnants cover larger distances, as can be seen in figure 13.

Under the influence of the black hole the course of the remnants changes. After ca 25 minutes they are still spiraling outwards, but then they start spiraling inwards again, being deflected towards the black hole. As soon as a remnant comes too close, it is drawn by the rotating accretion stream and swallowed by the black hole. Immediately a new remnant chord is expelled – and so in a musical sense the black hole could be regarded as a 'modulation machine'. The idea behind this is that black holes preserve light. Just as with the Big Bang, however, light will sooner or later escape, – 'modulated'...