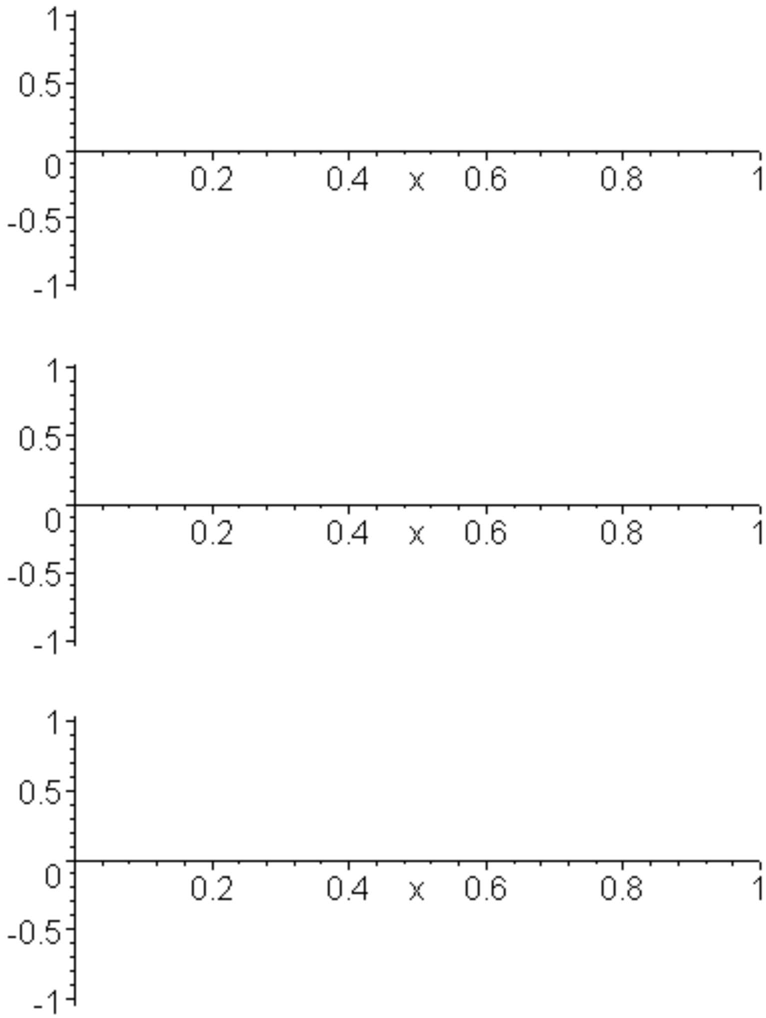
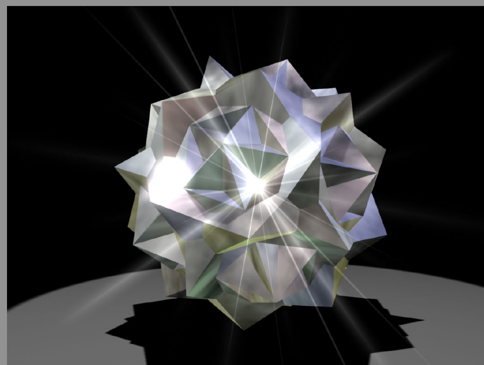
Physics and Music
PHY103



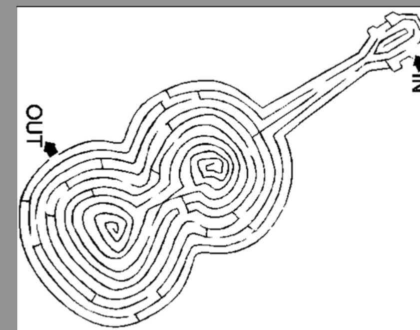
Approach for this class

Lecture 1

Animations from http://physics.usask.ca/~hirose/ep225/animation/standing1/images/



What does *Physics* have to do with *Music*?



1. Search for understanding of the natural world

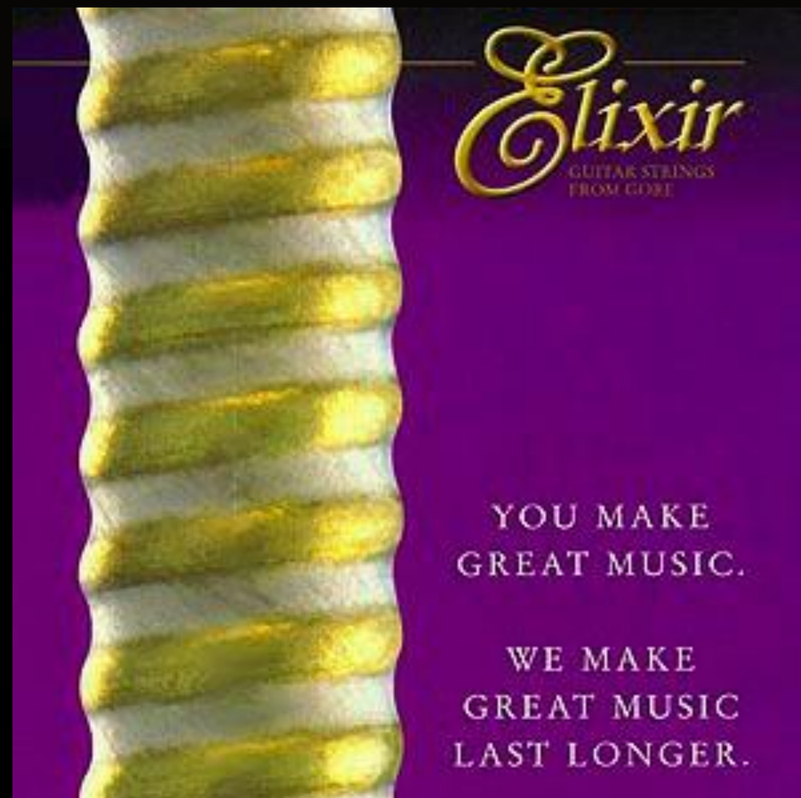
Quantitative theory. Physics provides a framework.

Linear 1D Wave equation describing waves on a guitar string has solutions that are traveling waves with speed $c = \sqrt{T / \rho}$
Using this you can predict the pitch of a string and how it depends on string density and tension.
However, if one tries to take into account other physical effects you get equations lacking simple solutions.

2. Method of Experimental Enquiry

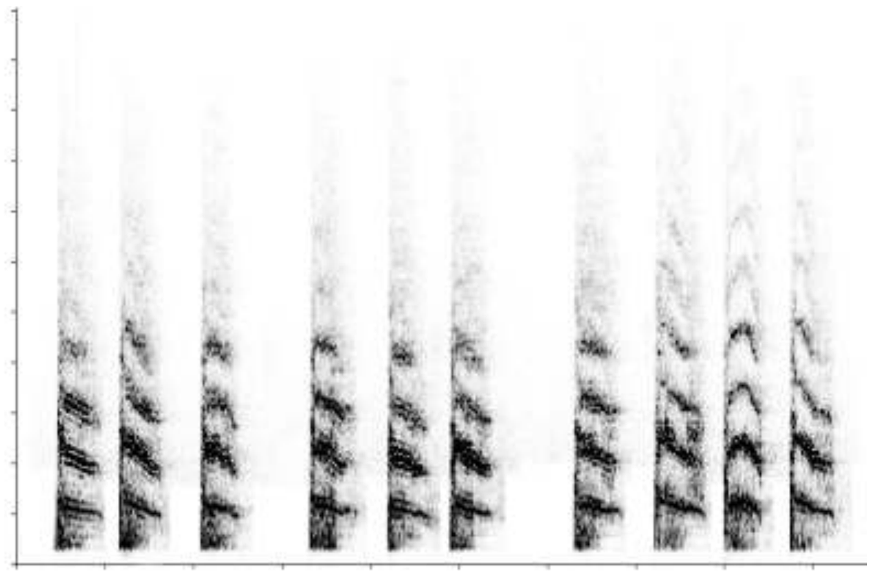
For example: By experimenting with different kinds of strings you might better understand what affects the damping time, "warmth" of tone, and durability.

Different scenarios and explanations can be tested via experiment.



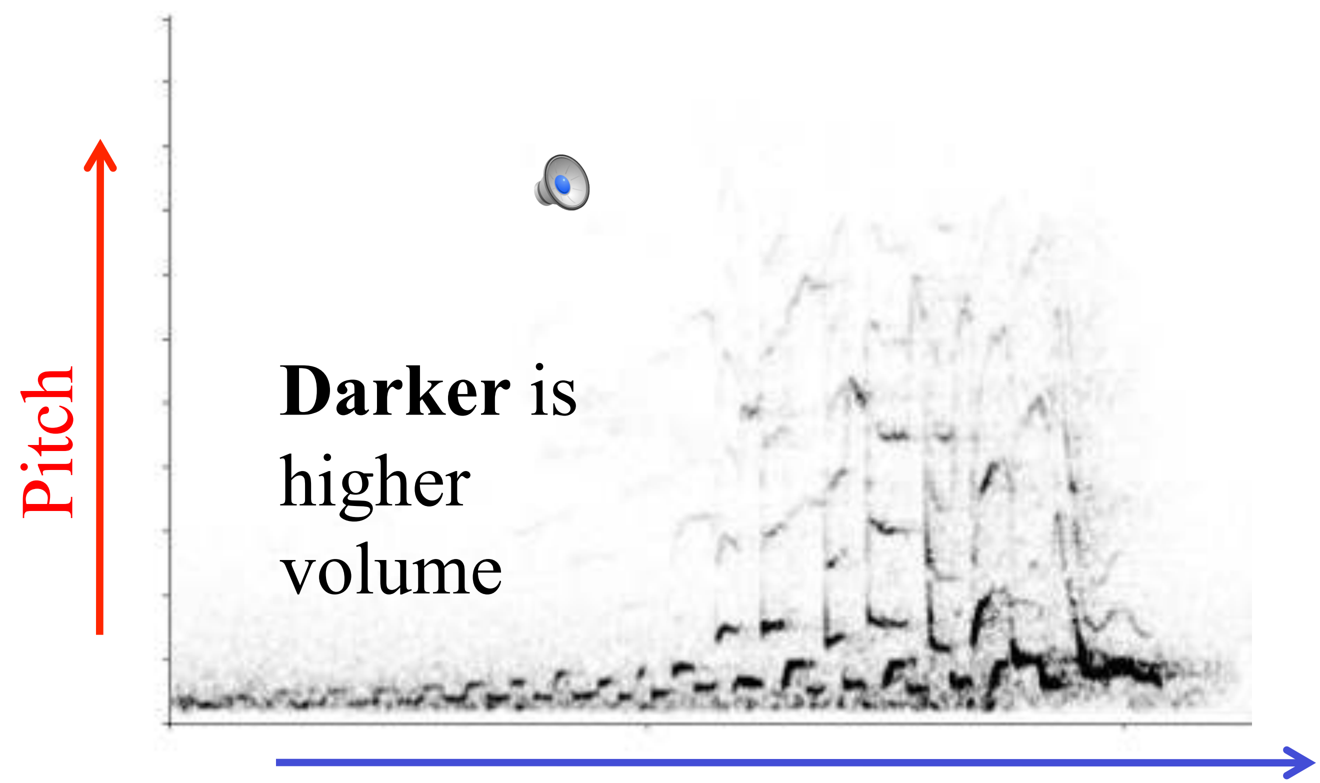
3. Source of ideas on how to vary the way we make/record music.

this is an mp3



Yucatan Brown Jay, copyright Daniel J. Mennill 1999

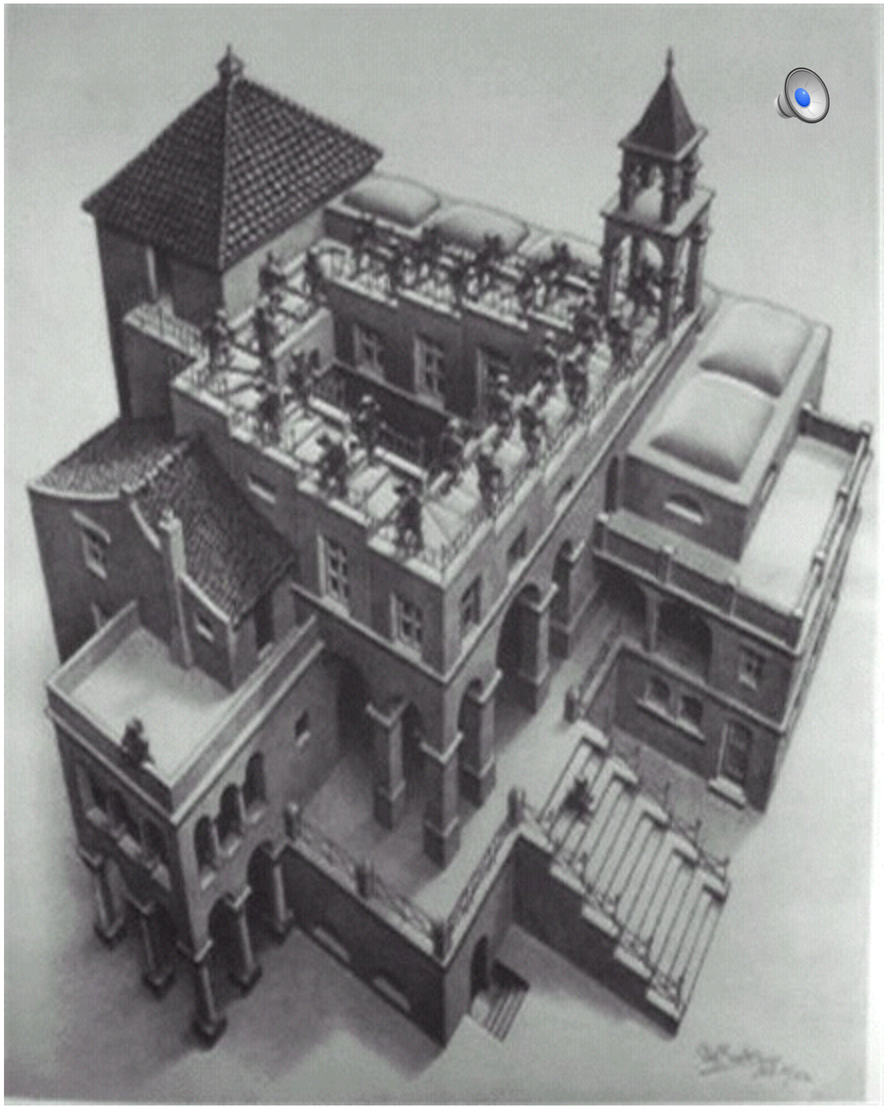
4. Hobby for physicists, musicians, craftsmen, engineers, psychologists and biologists



Montezuma Oropendola

Bird songs and spectra thanks to:

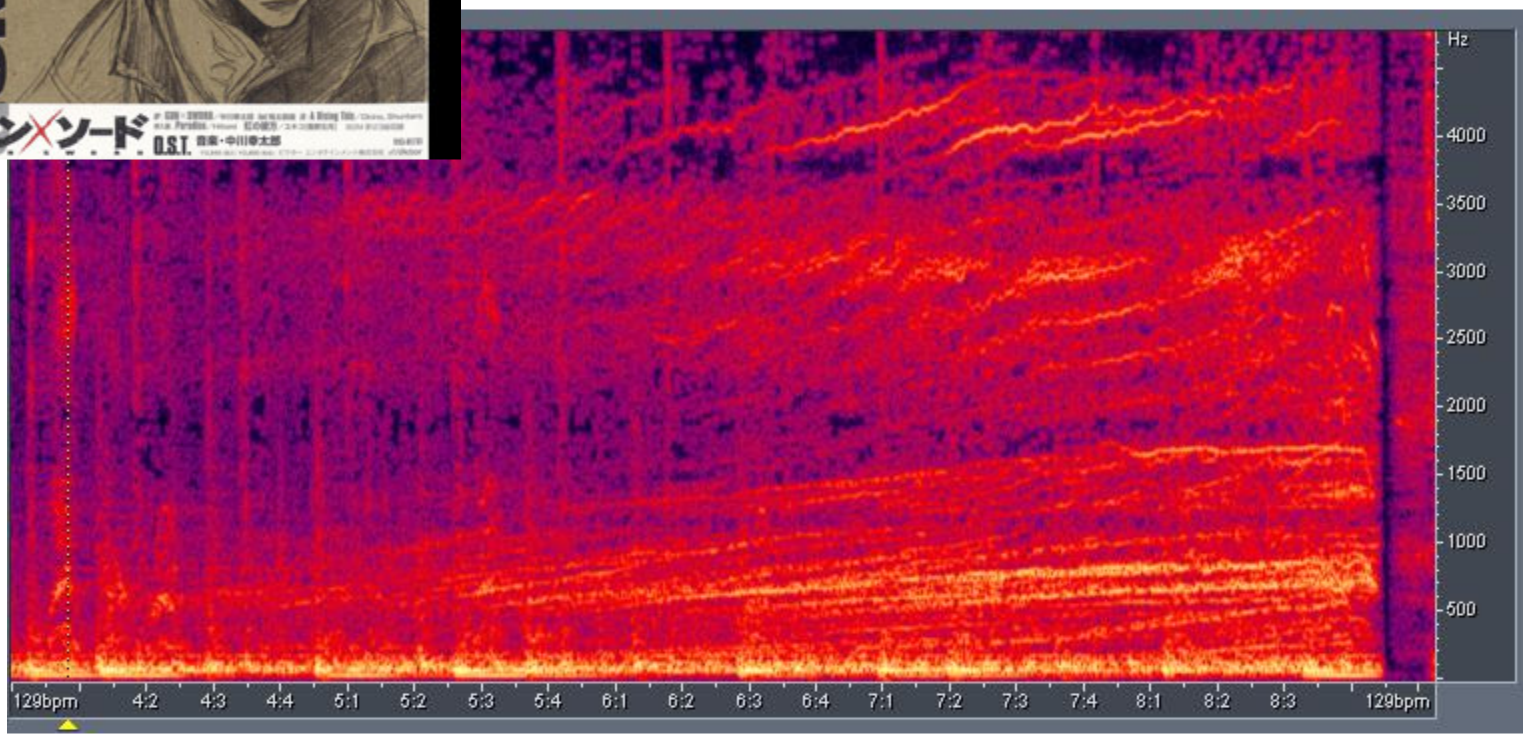
Daniel J. Mennill 1999



5. Physics of Perception: how does the ear and brain work?

Physics and Music together encompass a wide range of intertwined scientific disciplines and methods of enquiry

Opening song
from anime series



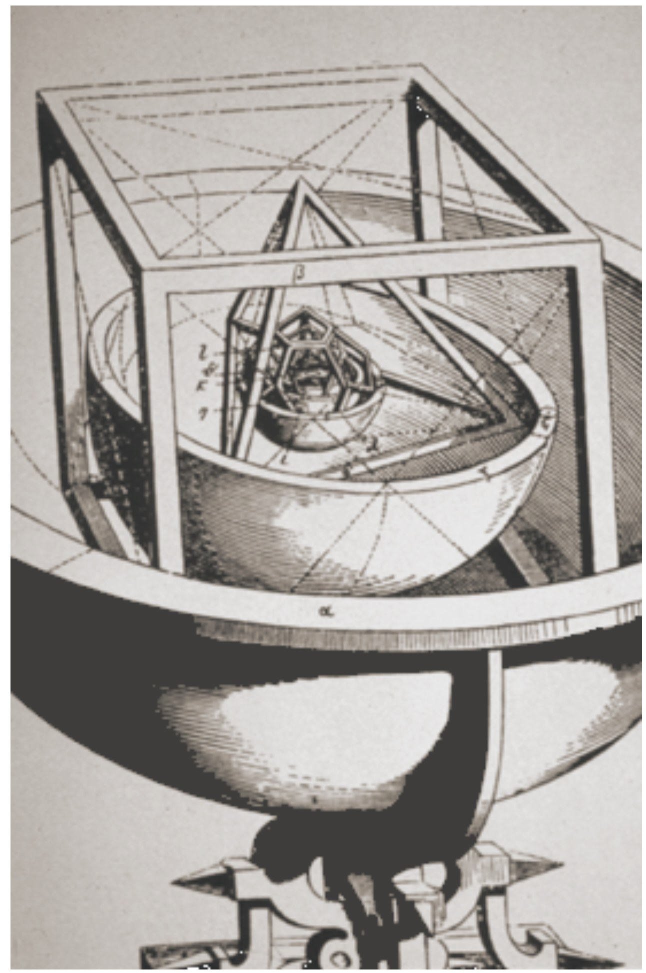
6. A way to find beauty in physics and math

- If physics can explain something musical then physics is beautiful.
  Pythagoras showed that musical intervals were related to rational numbers (like 2/3)
- If a physical model resembles an acoustic system it's more beautiful and therefore better. (Kepler)
- A way to explain physics. A way to catch people's interest. (Era of classical and modern physics). Deep connections between ideas of quantum mechanics and harmonic analysis.

from F Gafurio Theorica Musice 1492]
[rep. Wittkower 1949.]

Musical analogies in early astronomy and mathematics

"*The chief aim of all investigations of the external world should be to discover the* ***rational order and harmony*** *which has been imposed on it by God and which He revealed to us in the language of mathematics*." Johannes Kepler (1571-1630) from ***Astronomis Nova de Motibus***

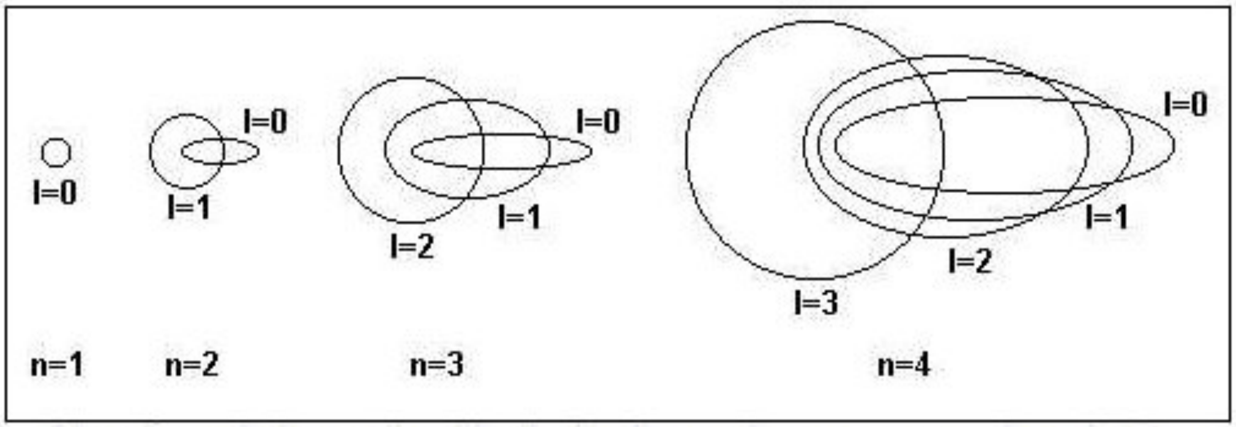


Kepler and the Music of the Spheres

In his book “Harmonies of the World”

“*The heavenly motions are nothing but a continuous song for several voices, to be perceived by the intellect not by the ear; a music which through discordant tension through syncopations and cadenzas as it were progresses toward certain pre-designed six voiced cadences and thereby sets landmarks in the immeasurable flow of time.*”

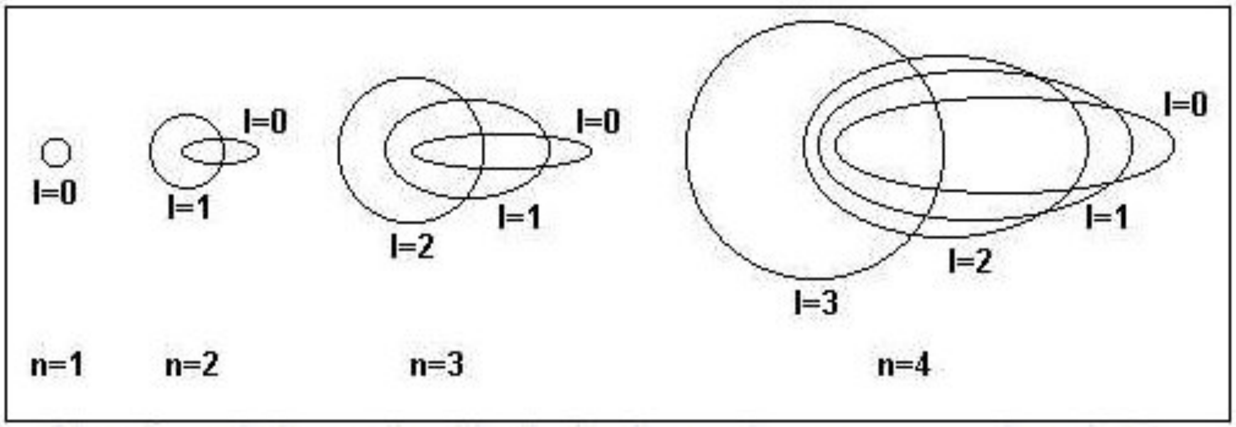
The Birth of Quantum Mechanics



The allowed electronic orbits for the four main quantum numbers by the Bohr-Sommerfeld model.

"Would Kepler, the mystic who, like Pythagoras and Plato, tried to find and to enjoy the harmonics of the Cosmos, would he have been surprised the atomic physics had rediscovered the very same harmonies in the building stones of matter and this in even purer form? For the integral numbers in the original quantum theory display a greater harmonic consonance than even the star in the Pythagorean music of the spheres"
--- Arnold Sommerfeld (1930)

The Birth of Quantum Mechanics



The allowed electronic orbits for the four main quantum numbers by the Bohr-Sommerfeld model.

Shroedinger equation is based on the wave equation.

This combined with boundary conditions yields various modes of oscillation that depend on integers --- just like harmonics of a string

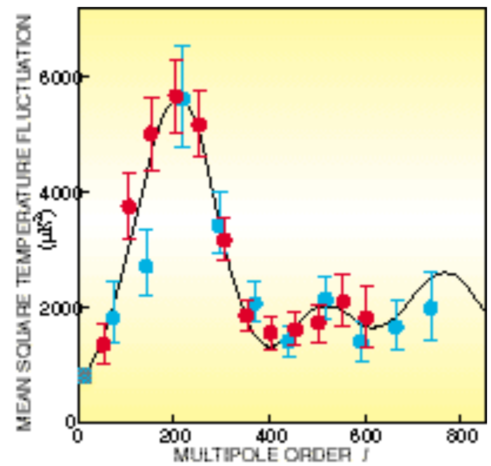
A resulting beautiful model for the quantization of the energy levels of the hydrogen atom

A nice analogy to Pythagorean approach --- the beauty of nature reflected or matched by simple integral/mathematical models

Musical analogies in modern physics

1996, Astrophysical Journal, 471, 30, Hu, Wayne, & White, Martin, ***Acoustic Signatures in the Cosmic Microwave Background***

"We study the uniqueness and robustness of acoustic signatures in the cosmic microwave background by allowing for the possibility that they are generated by some as yet unknown source of gravitational perturbations. The acoustic *pattern* of peak locations and relative heights predicted by the standard inflationary cold dark matter model is essentially unique and its confirmation would have deep implications for the causal structure of the early universe."



Power spectrum of spatial temperature fluctuations of the cosmic microwave background (from Physics Today)

August 2005 issue, Scientific American

"***Is the Universe Out of Tune***? Like the discord of key instruments in a skillful orchestra quietly playing the wrong piece, mysterious discrepancies have arisen between theory and observations of the "music" of the cosmic microwave background. Either the measurements are wrong or the universe is stranger than we thought." By Glenn D. Starkman and Dominik J. Schwarz

Approach for this class

- Exploration and search for understanding of natural world – the world of music
- Exploration of physical concepts and explanations via *experimentation*
- Demonstration and experimentation for fun
- Develop skills we need to do interesting experiments and to understand acoustic systems
- Understanding of musical instruments, how music is played and how we perceive it.
- Instruments represent centuries of experimentation and design - can we understand some of the compromises involved in their design? We will be building instruments in the lab.

Focus

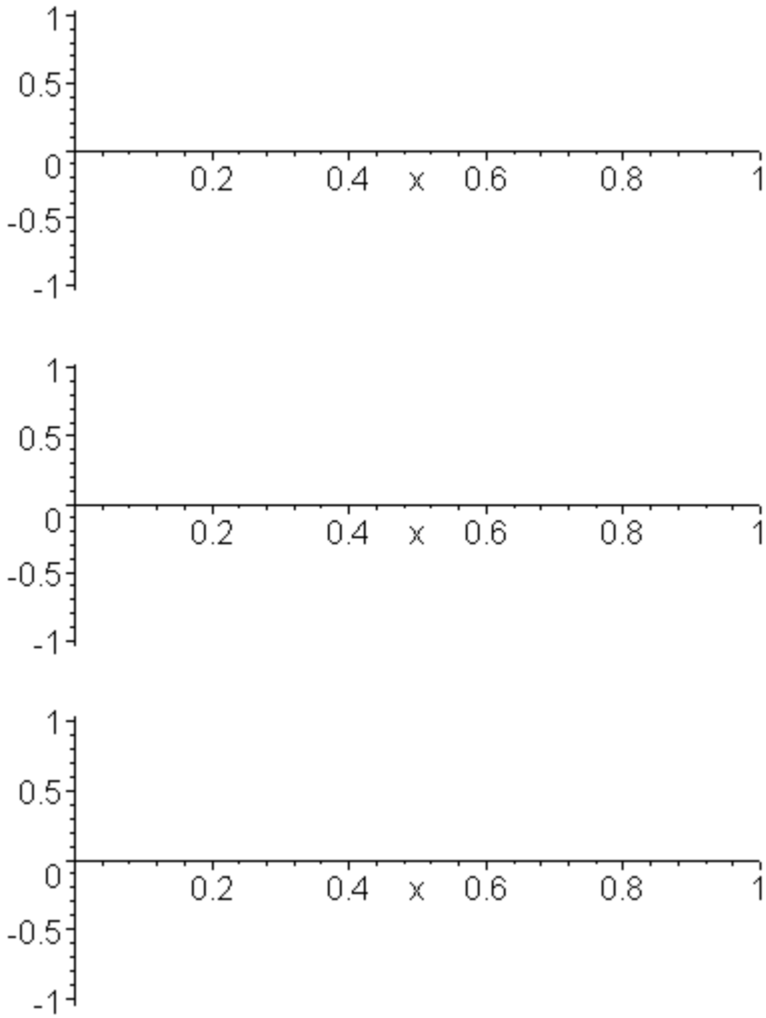
- Enquiry and Lab based.

------ This compliments other rich musical offerings on campus

- Follow our interests and our hunches. What topics would most likely lead to new undiscovered results or original creations?
- Tackle math/physics/engineering/computer skills sufficiently to allow us to investigate questions related to our interests.

Syllabus

- Harmonics and harmonic analysis
- Spectra of musical sounds/ timbre
- Resonances in a column of air
- Modes of oscillating membranes
- Sound waves, how they propagate, damp, reflect
- Scales, Tuning, history of scales, Atonal and Microtonal music
- Acoustics of wind instruments
- Acoustics of stringed instruments
- Acoustics of percussion instruments
- Loudness, physical measurement and units
- Room/concert hall acoustics
- Perception of sound – the ear and brain
- Perception of pitch and loudness
- Perception of music

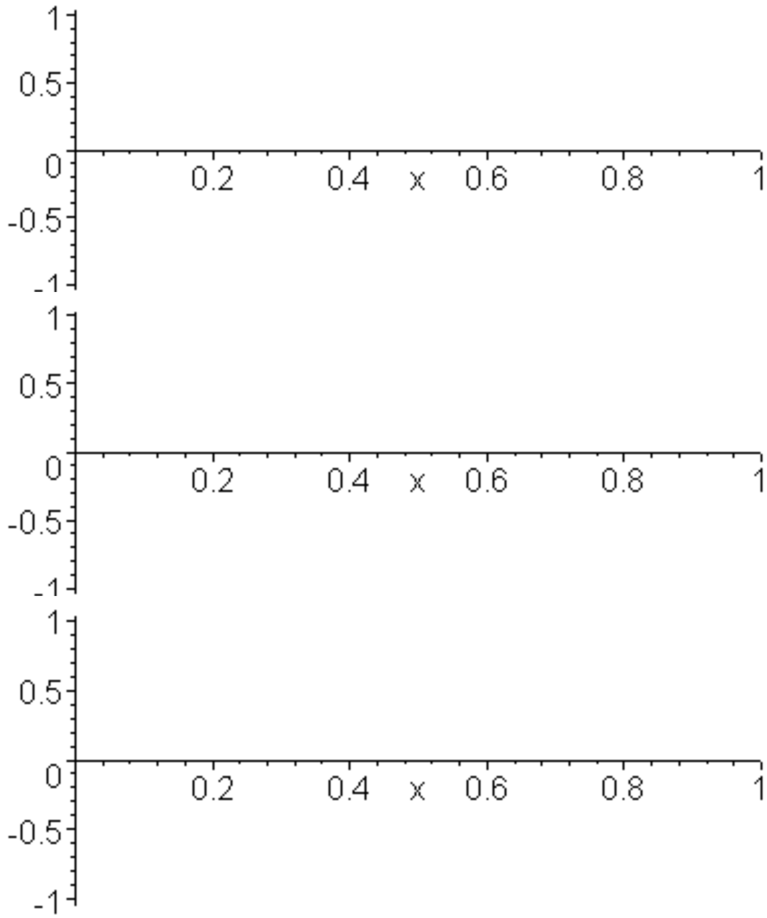


The musical string

Basis of some of investigations attributed to Pythagorus

Illustrates modes of oscillation and harmonics

Relation between intervals and wavelengths



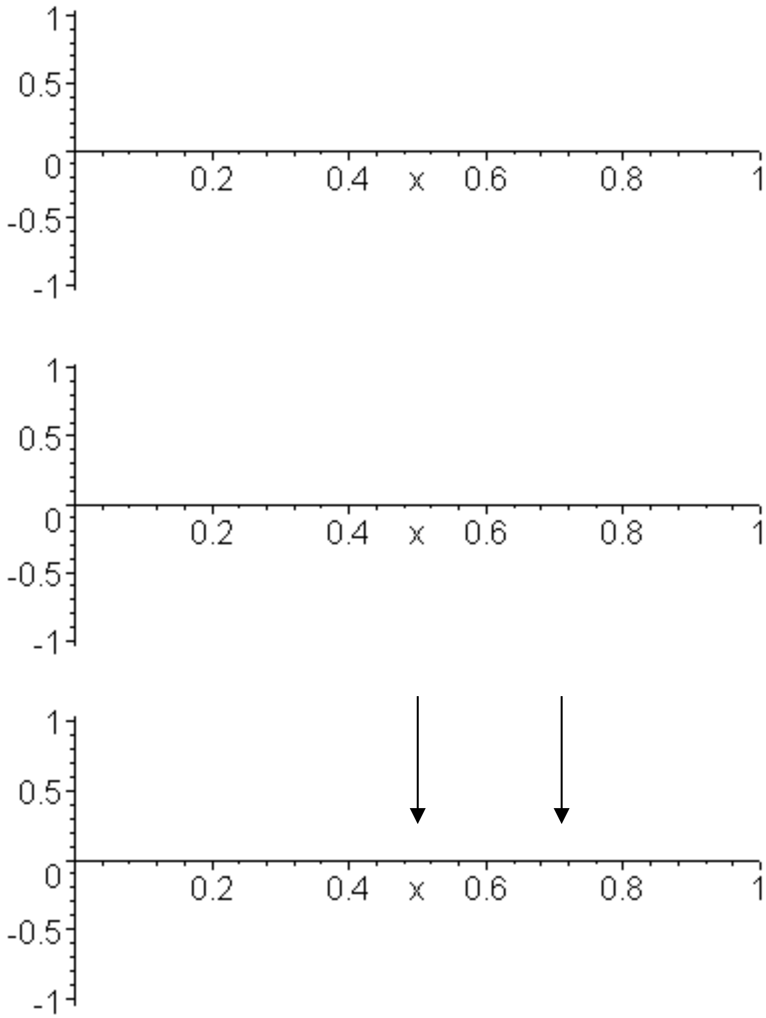
Fundamental

Octave – 1st harmonic

½ wavelength of fundamental

Octave+Fifth –2nd harmonic

1/3 wavelength of fundamental



Node, antinode

Where and how you pluck determines which modes excited and how much they are excited --with what amplitude

Harmonics or Overtones

Wavelengths

$$\lambda_1 = 2L$$

$$\lambda_2 = L = \lambda_1 / 2$$

$$\lambda_3 = 2L / 3 = \lambda_1 / 3$$

$$\lambda_4 = 2L / 4 = \lambda_1 / 4$$

$$\lambda_5 = 2L / 5 = \lambda_1 / 5$$

$$\lambda_6 = 2L / 6 = \lambda_1 / 6$$

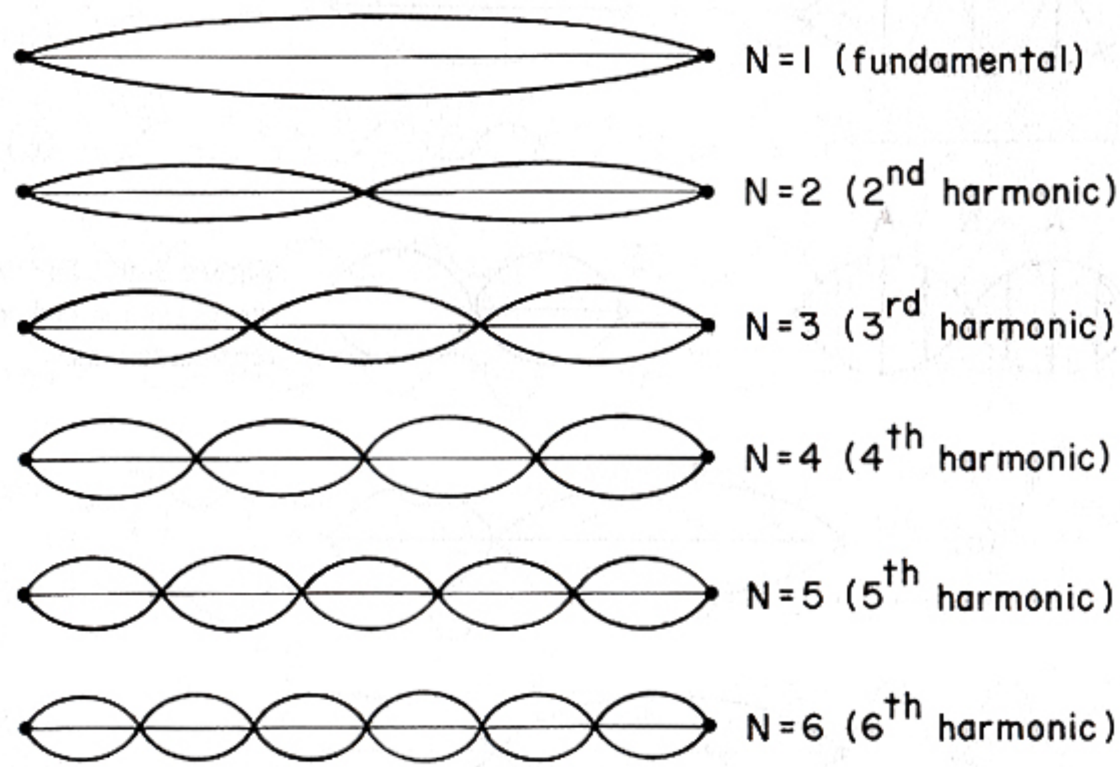


Figure 3–11 The representation of the first six possible standing waves in a stretched wire or rope.

Modes of oscillation

- When I use the word mode I mean that a motion takes place at a particular speed or rate. Cycles per second. This is called a frequency.
- Each mode of oscillation moves at a different frequency but it also has a particular spatial wavelength.

Wavelengths and frequencies of Harmonics

TABLE 3–2 WAVELENGTHS AND FREQUENCIES OF THE FIRST SIX POSSIBLE STANDING WAVES ON A STRING OF LENGTH L

Harmonic number N	Wavelength	Frequency $\left(f = \frac{v}{\lambda}\right)$
1	$\lambda_1 = 2L$	$f_1 = \frac{v}{2L}$
2	$\lambda_2 = L = \frac{1}{2}\lambda_1$	$f_2 = \frac{v}{L} = 2f_1$
3	$\lambda_3 = \frac{2}{3}L = \frac{1}{3}\lambda_1$	$f_3 = \frac{v}{\frac{2}{3}L} = 3f_1$
4	$\lambda_4 = \frac{L}{2} = \frac{1}{4}\lambda_1$	$f_4 = \frac{v}{\frac{1}{2}L} = 4f_1$
5	$\lambda_5 = \frac{2}{5}L = \frac{1}{5}\lambda_1$	$f_5 = \frac{v}{\frac{2}{5}L} = 5f_1$
6	$\lambda_6 = \frac{L}{3} = \frac{1}{6}\lambda_1$	$f_6 = \frac{v}{\frac{1}{3}L} = 6f_1$

Overtones of the string

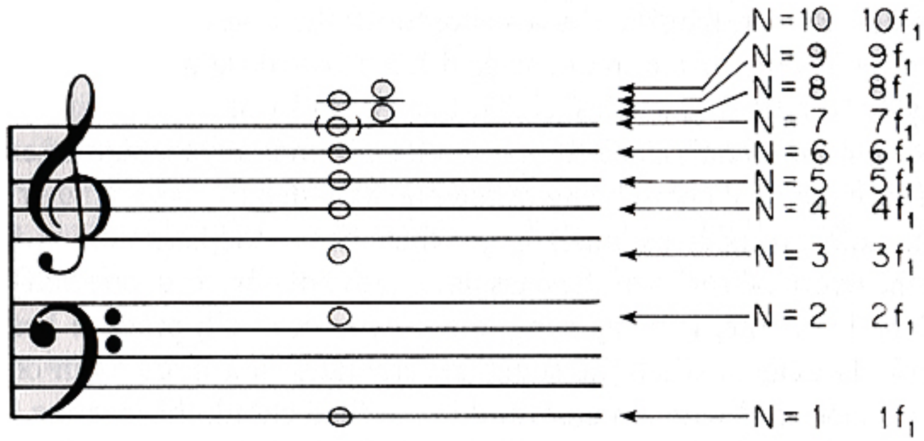
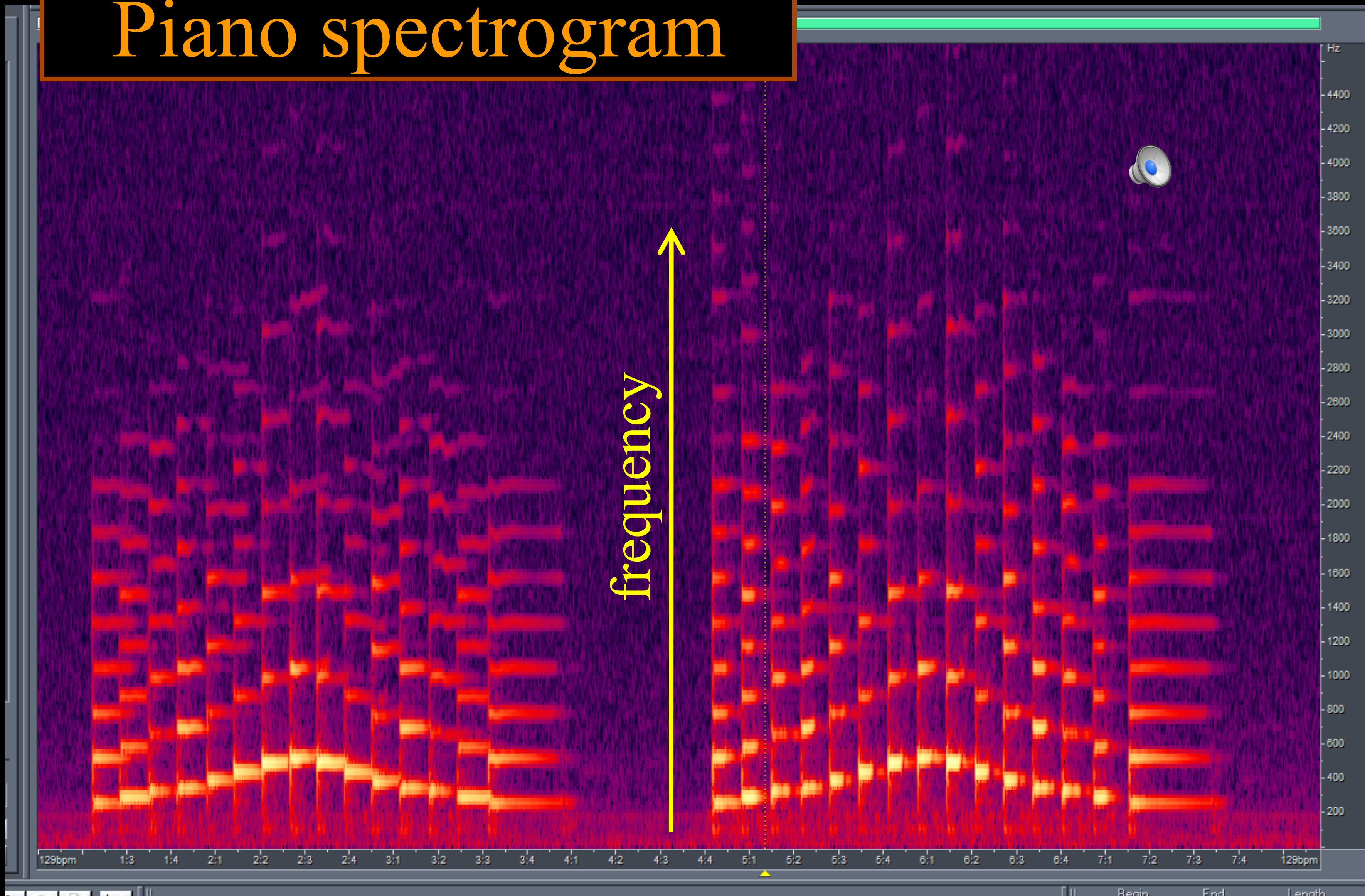


Figure 3–12 Notes on the musical staff having frequencies closest to the notes in the overtone series of G_2; each note is labeled by its harmonic number and the frequency of the corresponding harmonic.

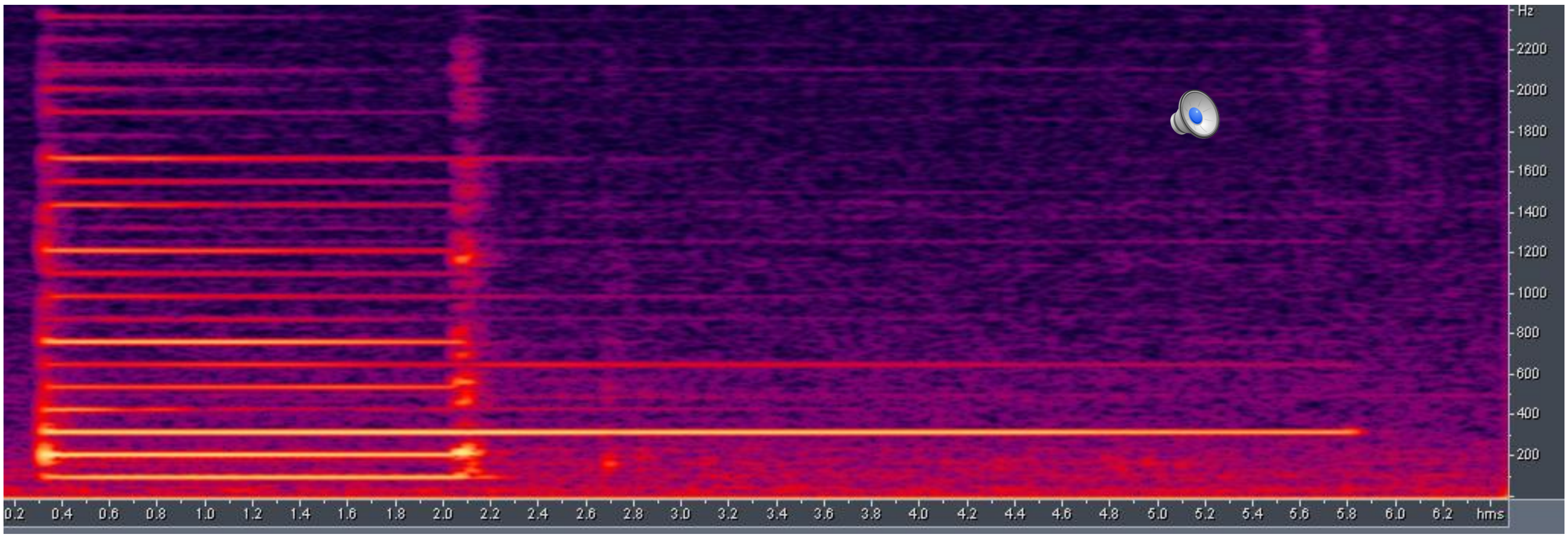
TABLE 3–3 MUSICAL INTERVALS BETWEEN THE FUNDAMENTAL AND OTHER NOTES OF THE OVERTONE SERIES

N	f	Interval
1	f_1	Unison
2	$2f_1$	One octave
3	$3f_1$	One octave + one perfect fifth
4	$4f_1$	Two octaves
5	$5f_1$	Two octaves + one major third
6	$6f_1$	Two octaves + one perfect fifth
7	$7f_1$	Two octaves + one minor seventh
8	$8f_1$	Three octaves

Piano spectrogram



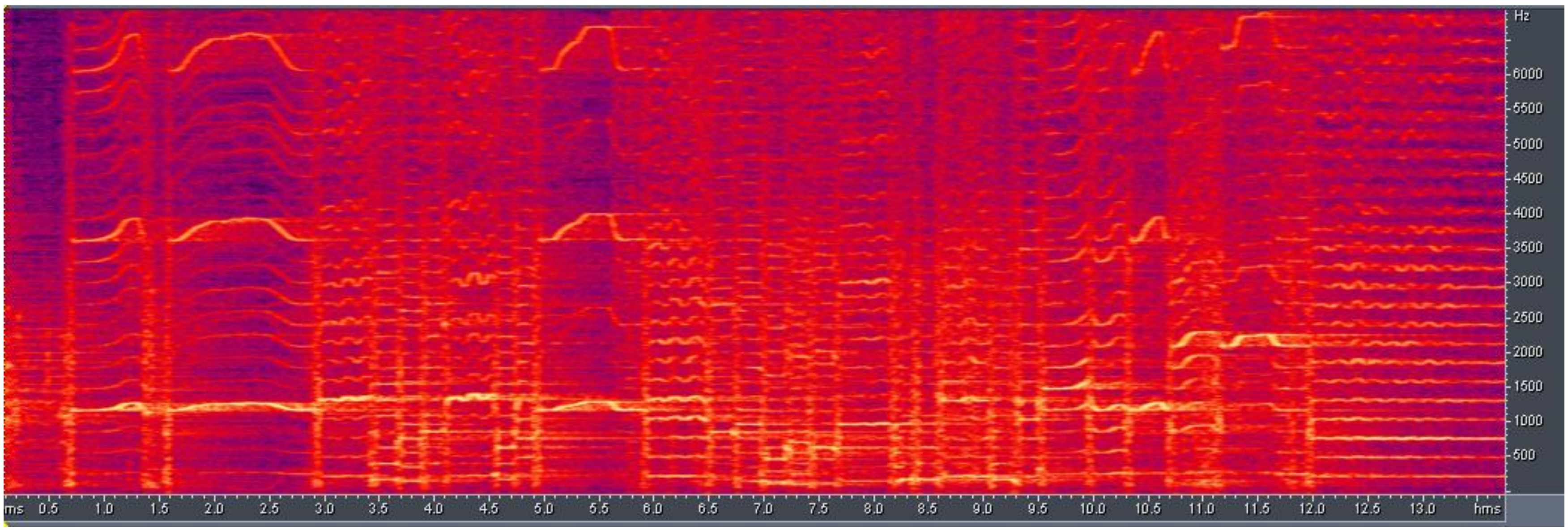
Touching the string at a node after plucking



Playing the A string of an electric guitar and then touching the string lightly over the 7th fret

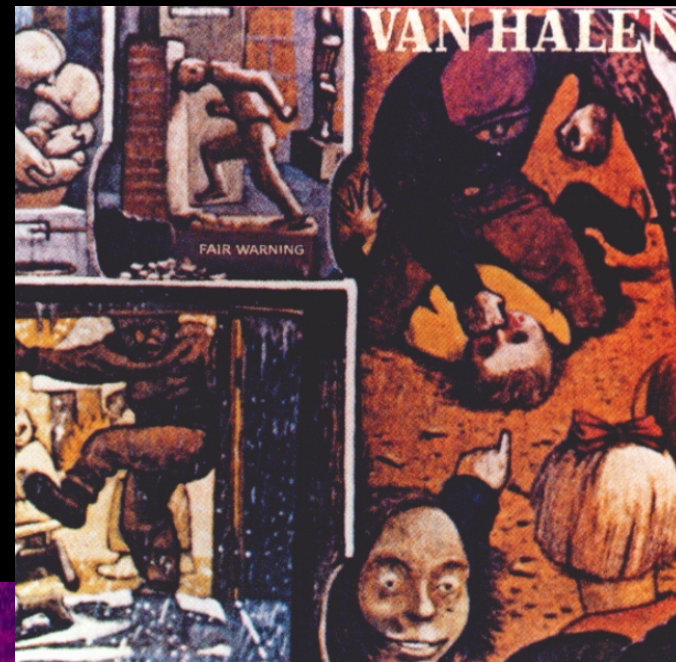
All modes are excited by plucking, most damped after finger touches the string

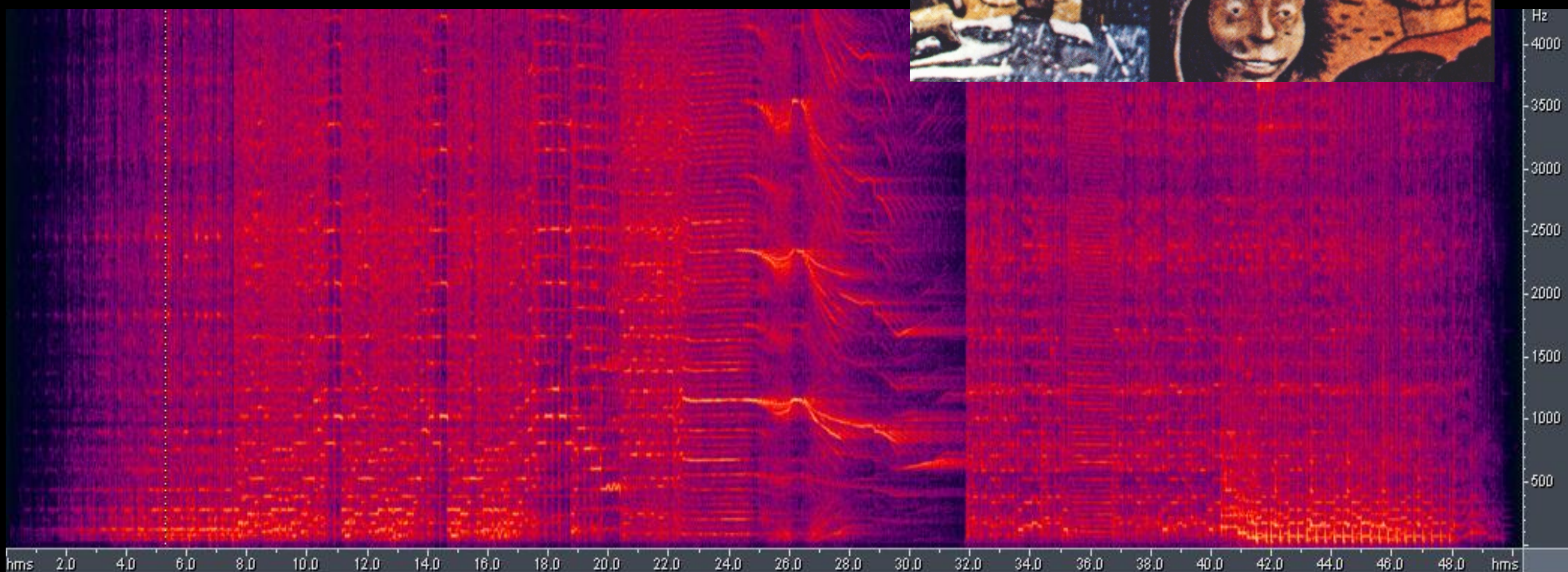
`Natural' harmonics technique



from an on-line guitar lesson by Eric van den berg

‘Natural’ Harmonics in Music





Intro to Mean Street

Pitch and frequency

- Qualitatively we have related wavelength on a string to a speed of string oscillation or frequency
- Qualitatively we have related the pitch we perceive to a frequency.

Mode of oscillation

Pitch ↔ Frequency ↔ Wavelength

Terms Introduced

- Fundamental
- Wavelength
- Interval
- Harmonic
- Mode of oscillation
- Antinode and node
- Octave
- Amplitude
- Overtone
- Pitch
- Frequency

Recommended reading

- Hopkin Chap 2 pages 7-18 on acoustics
- Hopkin Chap 9 pages 117-122 on Chordophones
- Berg and Stork Chap 3 pages 66-76 or Benade Chap 7

Reserve list in POA library

Xerox list of many chapters on my web site, same password and user name!