OSHER LIFELONG LEARNING INSTITUTE

Sound of Music

How It Works

Session 5

Musical Instruments

OLLI at Illinois

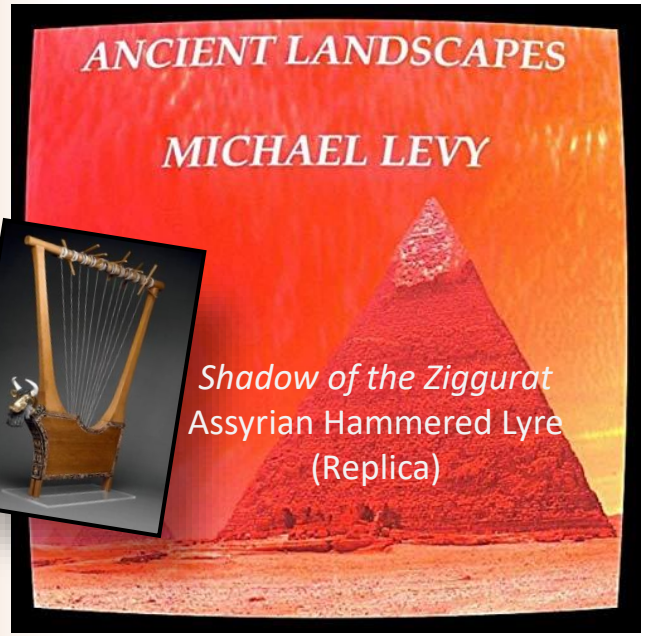
Spring 2020

D. H. Tracy

OSHER LIFELONG LEARNING INSTITUTE

Sound of Music

How It Works



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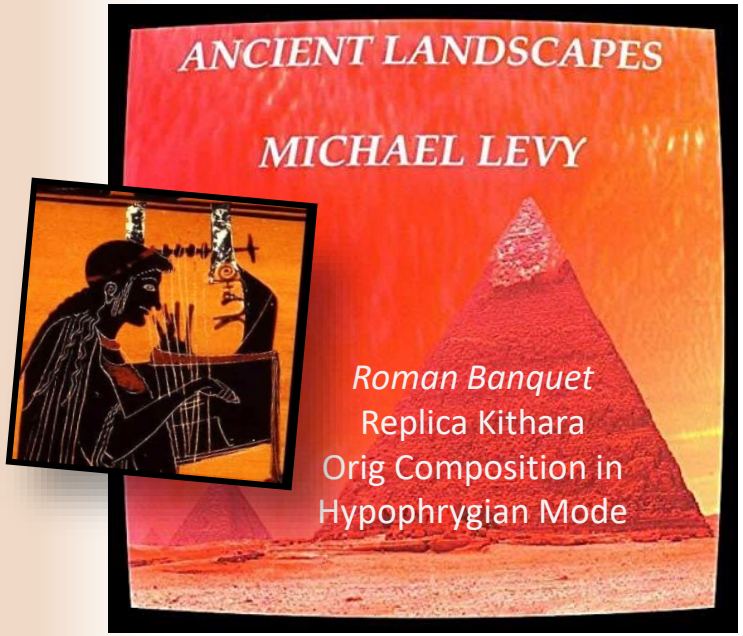

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If You Missed a Session….

- PDF's of previous presentations
  - Also other handout materials

  are on the OLLI Course website:

  http://olli.illinois.edu/downloads/courses/

If you have questions, contact me by email

Right Now

The Sound of Music Syllabus.pdf
References for Sound of Music OLLI Course Spring 2020.pdf
Smartphone Apps for Sound of Music.pdf
Musical Scale Cheat Sheet.pdf
OLLI Musical Scale Slider Tool.pdf

SoundOfMusic_1 handout.pdf
SoM_2_handout.pdf
SoM_3 handout.pdf
SoM_4 handout.pdf

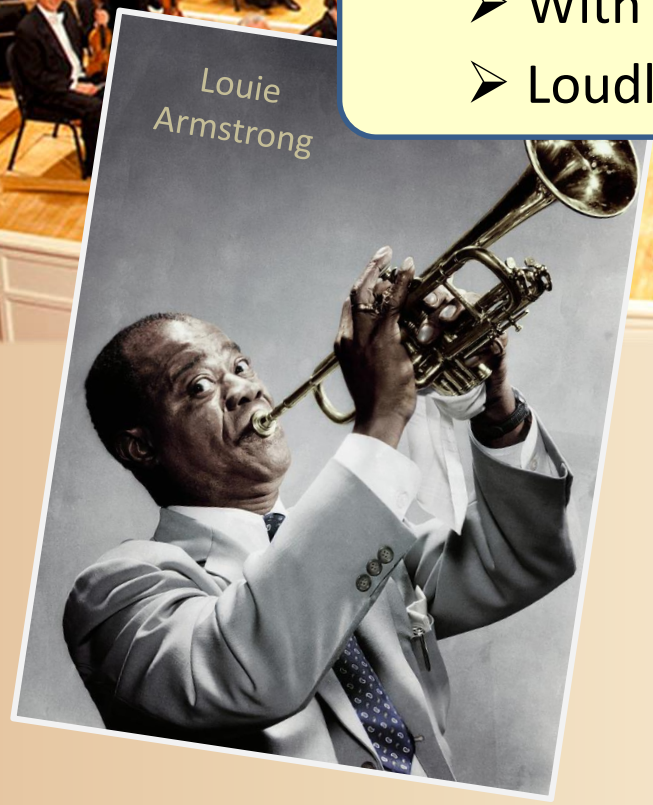
Course Outline

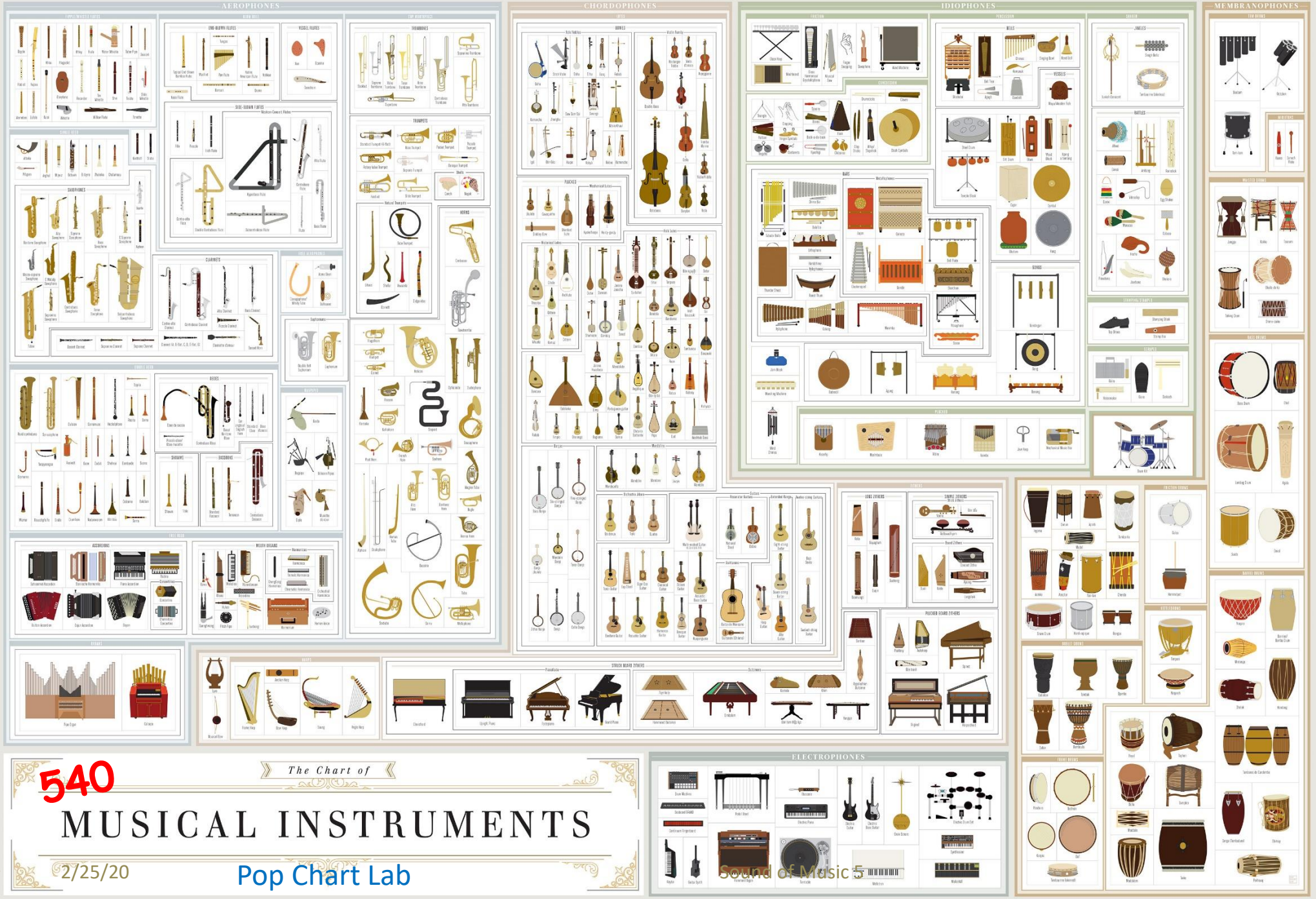
1. Building Blocks: Some basic concepts
2. Resonance: Building Sounds
3. Hearing and the Ear
4. Musical Scales
5. **Musical Instruments**
6. Singing and Musical Notation
7. Harmony and Dissonance; Chords
8. Combining the Elements of Music

Chicago Symphony Orchestra (2015)

Basic Role of Musical Instruments is:

- Rendering Musical Notes or Rhythmic Beats
  - With pleasing Timbres
  - Loudly enough to be heard

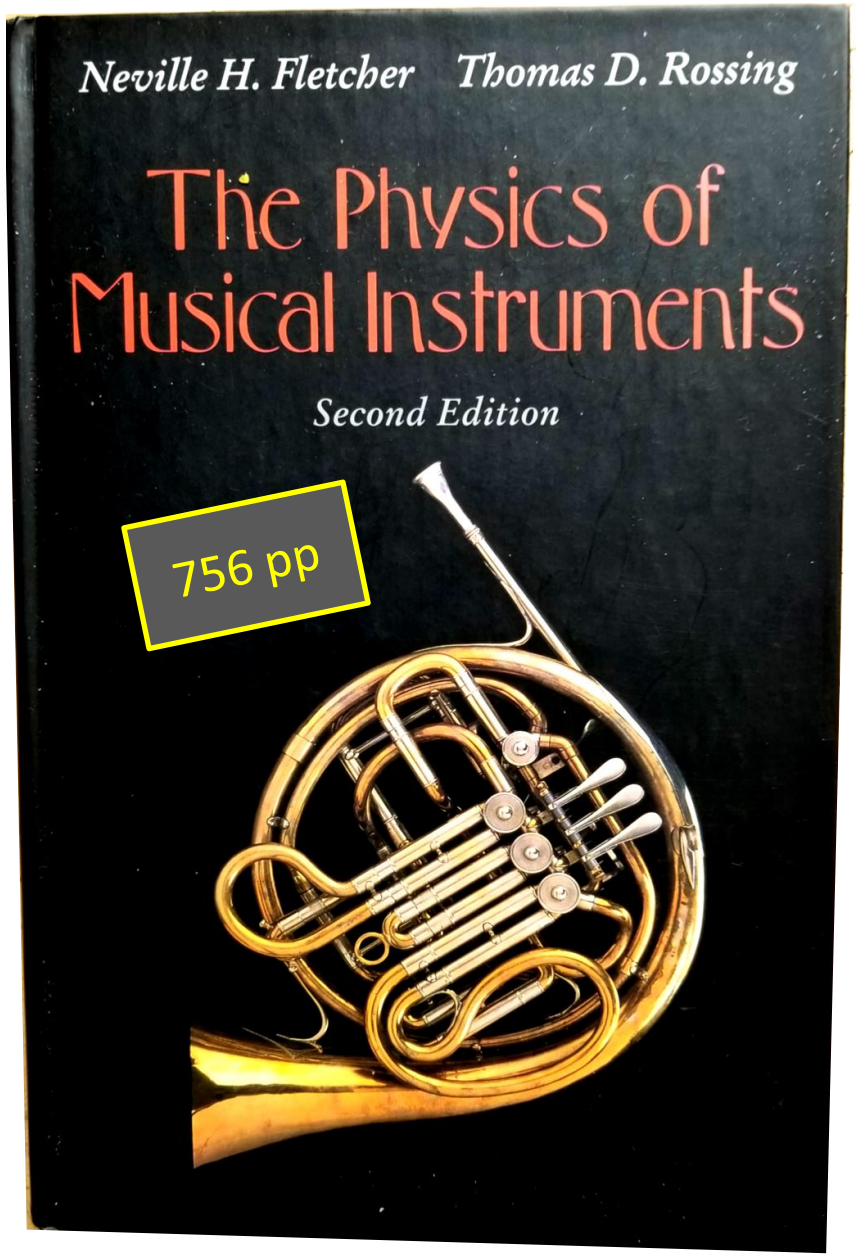




We have a few to get through…

How Much Is Known About Musical Instruments?

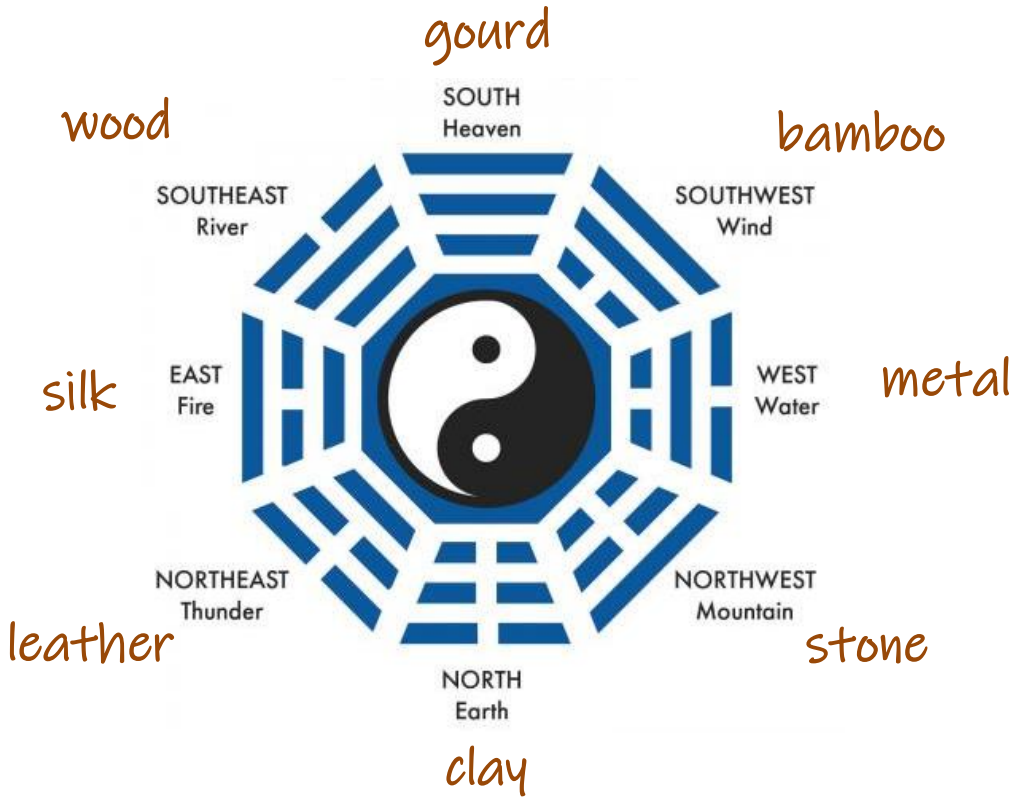
- Not that much
- Good general understanding
  - Lots of interesting details
    - but not enough to design one from scratch
  - Lots of poorly understood aspects
- Existing instruments basically evolved over centuries
  - largely by trial and error
  - but often with informed insight



Classifying Musical Instruments

- Traditionally
  - Strings
  - Brasses
  - Woodwinds
  - Percussion

Chinese "8 Winds" Classification (~ Han Dynasty)



Hornbostel-Sachs Classification System

The Dewey Decimal System of Musical Instruments

1914

Erich von Hornbostel
(1877-1935)

Curt Sachs
(1881-1959)

① Idiophones

Whole thing vibrates

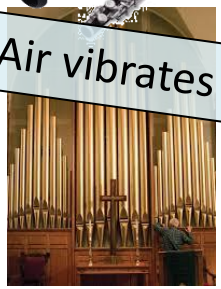
② Membranophones

Membrane vibrates

③ Chordophones

Strings vibrate

④ Aerophones



Air vibrates

⑤ Electrophones

Electrons vibrate?

Hornbostel-Sachs: Family Tree of the African Thomo

3 Chordophones

31 Simple chordophones or zithers

311 Bar zithers

311.1 Musical bows

311.12 Heterochord musical bows

311.121 Mono-heterochord musical bows

311.121.2 With resonator

311.121.22 With resonator attached

311.121.221 Without tuning noose *S. Africa (hade, thomo)*

MIMO uses Hornbostel-Sachs to classify their collections

www.MIMO-International.com

MIMO
musical instrument museums online

Explore the world collections of musical instruments

Welcome to the world's largest freely accessible database for information on musical instruments held in public collections. Our database now contains the records of **64070 instruments**.

SEARCH

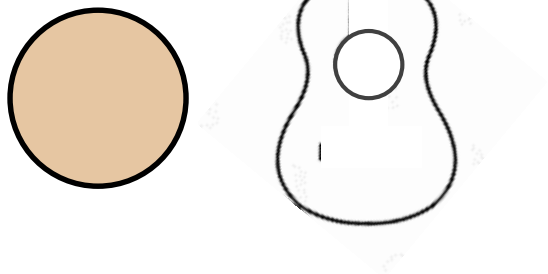
INSTRUMENT FAMILIES | MUSEUMS | INSTRUMENT MAKERS

NEWS

CITÉ DE LA MUSIQUE PHILHARMONIE DE PARIS
THE UNIVERSITY of EDINBURGH
GERMANISCHES NATIONAL MUSEUM
mim
GALLERIA DELL'ACCADEMIA DI FIRENZE
SCENKONST MUSEET
Africa TERVUREN
MUSEU DE LA MÚSICA
ROYAL COLLEGE OF MUSIC
Ethnologisches Museum Staatliche Museen zu Berlin
CIMCIM
SOINUENEA Herri Musikaren Txokoa
Studi Università degli Studi di Torino

My Scheme

- 1 Dimensional Resonators
  - Strings
  - Pipes
- 2 Dimensional Resonators
  - Drums
  - Parts of some string instruments (e.g. guitars, pianos)
- 3 Dimensional Resonators
  - Bars (e.g. xylophones)
  - Bells



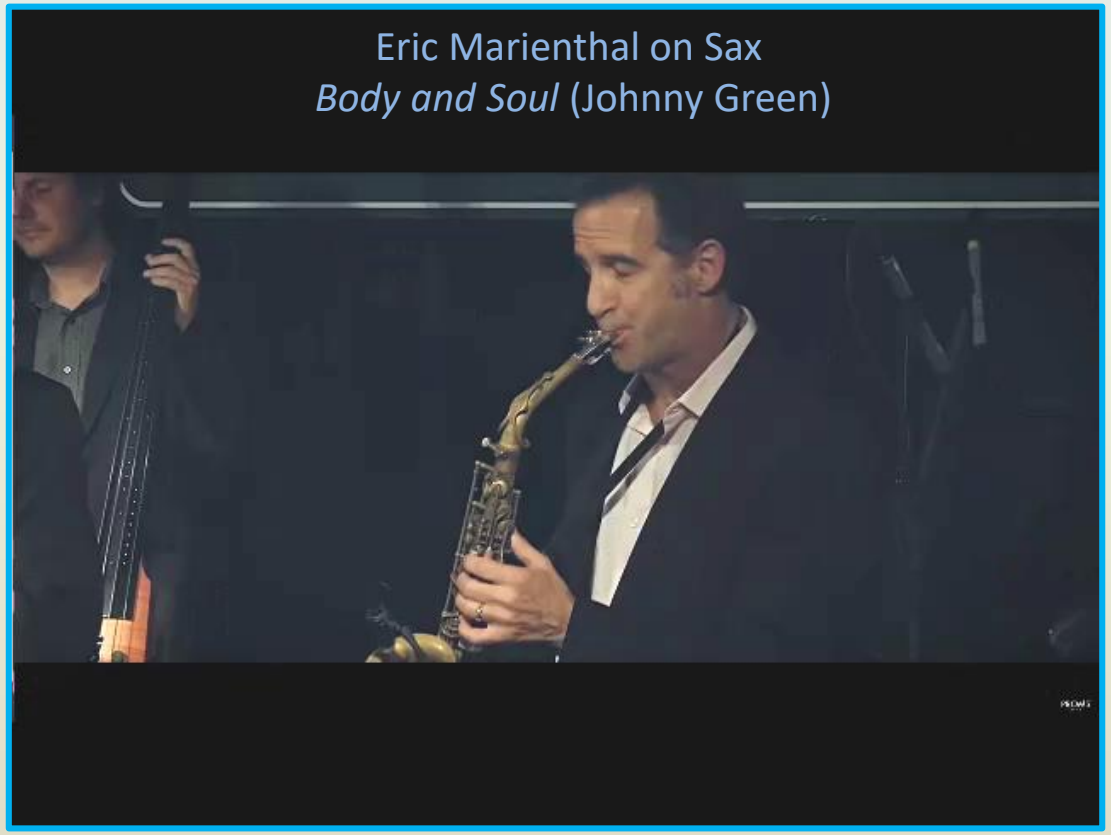
11 Reasons to Choose An Instrument

11 Reasons to Choose An Instrument

1. Timbre

Emmanuel Pahud on Flute
Syrinx (Debussy)

Eric Marienthal on Sax
Body and Soul (Johnny Green)



11 Reasons to Choose An Instrument

1. Timbre

2. Range

11 Reasons to Choose An Instrument

1. Timbre
2. Range
3. **Chord Capability**

Simultaneous Notes

Sharon Kam-Basset on Clarinet
Clarinet Concerto (Mozart)

Richard Elliott on Salt Lake Tabernacle Pipe Organ
Bach *Toccata in D Minor*

11 Reasons to Choose An Instrument

1. Timbre
2. Range
3. Chord Capability
4. **Loudness**

Gudrun Hinze on Piccolo
"TWEET" (Daniel Dorff)

Alison Balsom on Trumpet
Trumpet Concerto in E flat Major (Hummel)

11 Reasons to Choose An Instrument

1. Timbre
2. Range
3. Chord Capability
4. Loudness
5. **Expressiveness**

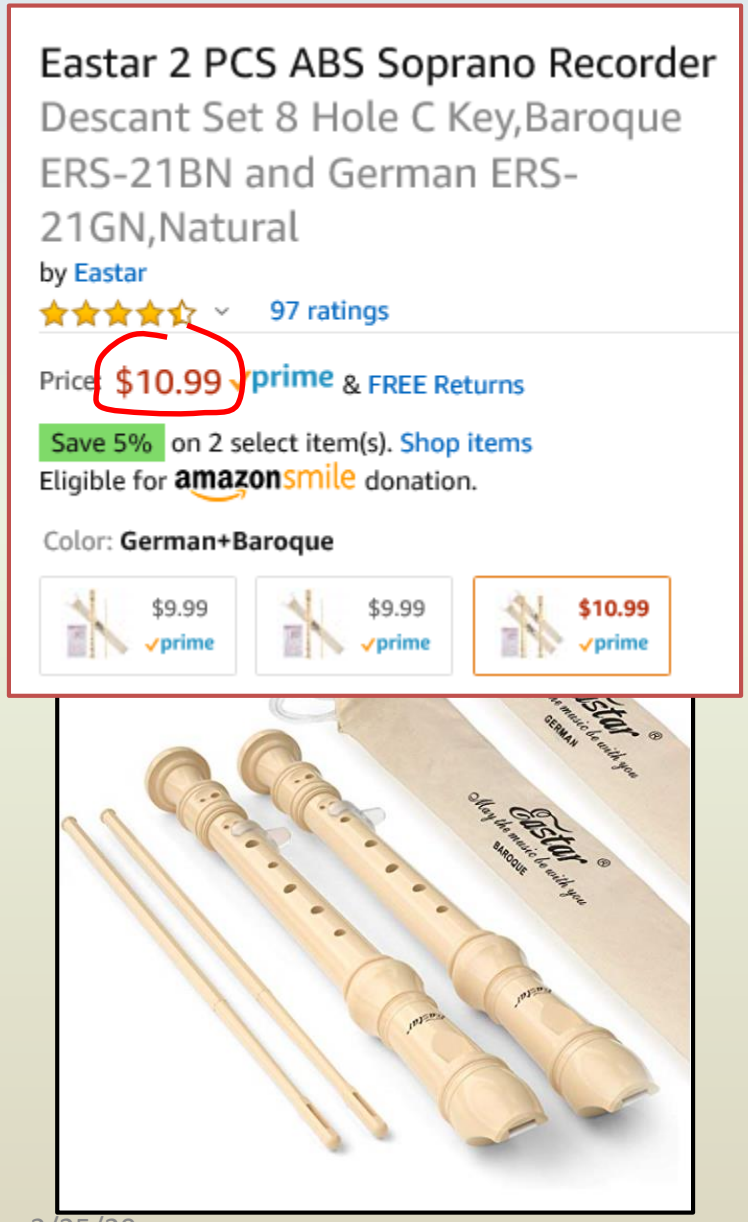
Joyce Lindorff on Harpsichord
Wassermusik (Händel)

Harry Völker on Piano
Wassermusik (Händel)

11 Reasons to Choose An Instrument

1. Timbre
2. Range
3. Chord Capability
4. Loudness
5. **Expressiveness**

11 Reasons to Choose An Instrument



1. Timbre
2. Range
3. Chord Capability
4. Loudness
5. Expressiveness
6. **Cost/Availability**

11 Reasons to Choose An Instrument

1. Timbre
2. Range
3. Chord Capability
4. Loudness
5. Expressiven
6. Cost/Availab
7. **Portability**

11 Reasons to Choose An In

1. Timbre
2. Range
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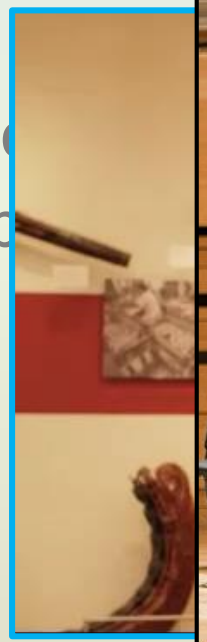
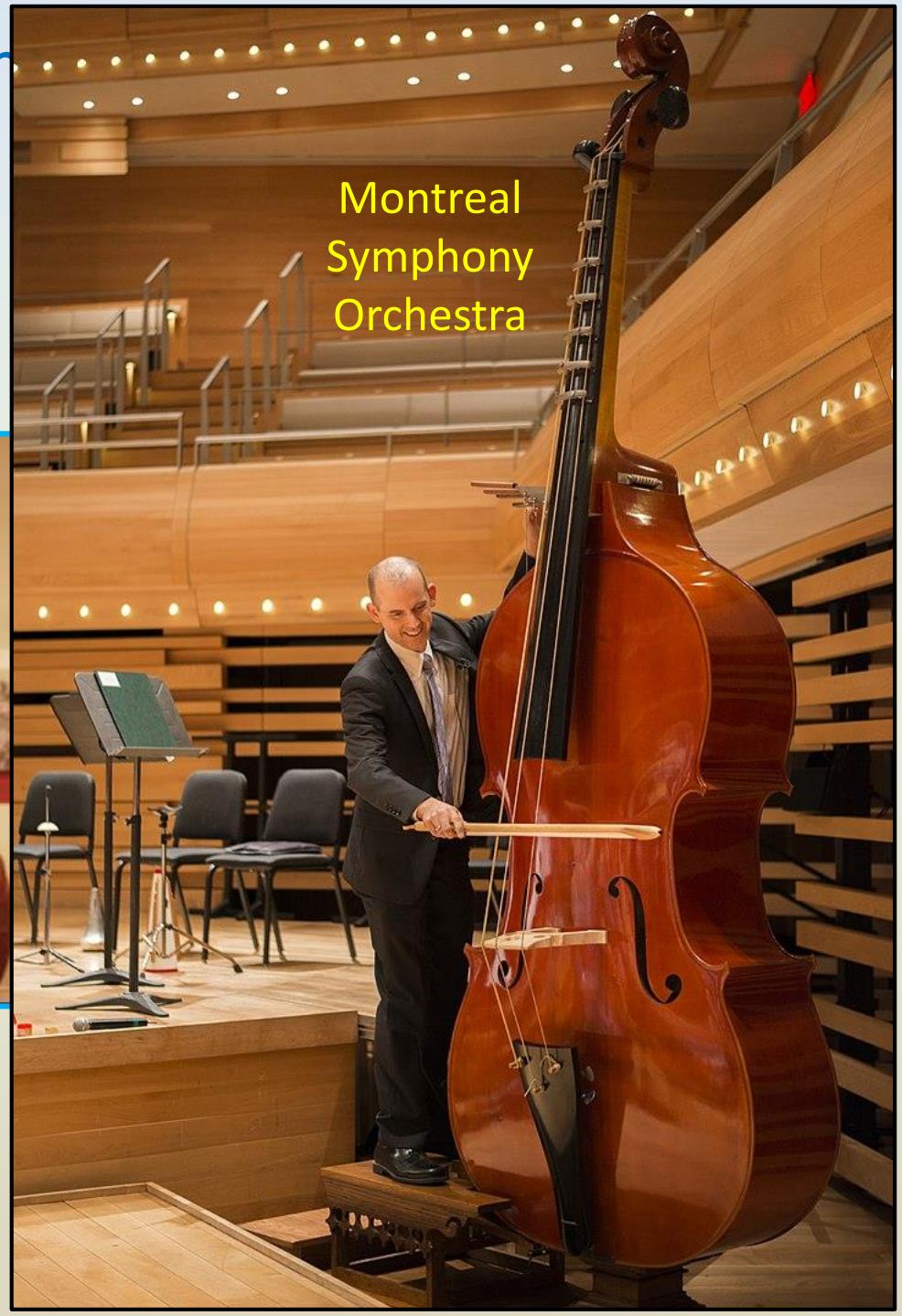
4. Loudness
5. Expressiven
6. Cost/Availab
7. **Portability**





11 Reasons to Choose An Instrument

1. Timbre
2. Range
3. Chord Capability
4. Loudness
5. Expressiveness
6. Cost/Availability
7. Portability
8. **Ease of Playing**

11 Reasons to Choose An Instrument

1. Timbre
2. Range
3. Chord Capability
4. Loudness
5. Expressiveness
6. Cost/Availability
7. Portability
8. Ease of Playing
9. **Stability of Tuning**

Electronic Synthesizer:
Incredibly Stable

11 Reasons to Choose An Instrument

1. Timbre
2. Range
3. Chord Capability
4. Loudness
5. Expressiveness
6. Cost/Availability
7. Portability
8. Ease of Playing
9. Stability of Tuning
10. **Awesomeness**

11 Reasons to Choose An Instrument

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11 Reasons to Choose An Instrument

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1. Timbre
2. Range
3. Chord Capability
4. Loudness
5. Expressiveness
6. Cost/Availability
7. Portability
8. Ease of Playing
9. Stability of Tuning
10. Awesomeness
11. **Cultural Conventions**

Archy J in music video *Nageena -- Enchantress of the Deserts (2019)*

11 Reasons to Choose An Instrument

1. Timbre
2. Range
3. Chord Capability
4. Loudness
5. Expressiveness
6. Cost/Availability
7. Portability
8. Ease of Playing
9. Stability of Tuning
10. Awesomeness
11. Cultural Conventions

Timbre

Soprano Sax

Clarinet (B♭)

Fundamental

262 Hz (C4)

Bassoon

Trumpet

Oboe

Cello
(G String)
Bowed
Plucked

Tuba

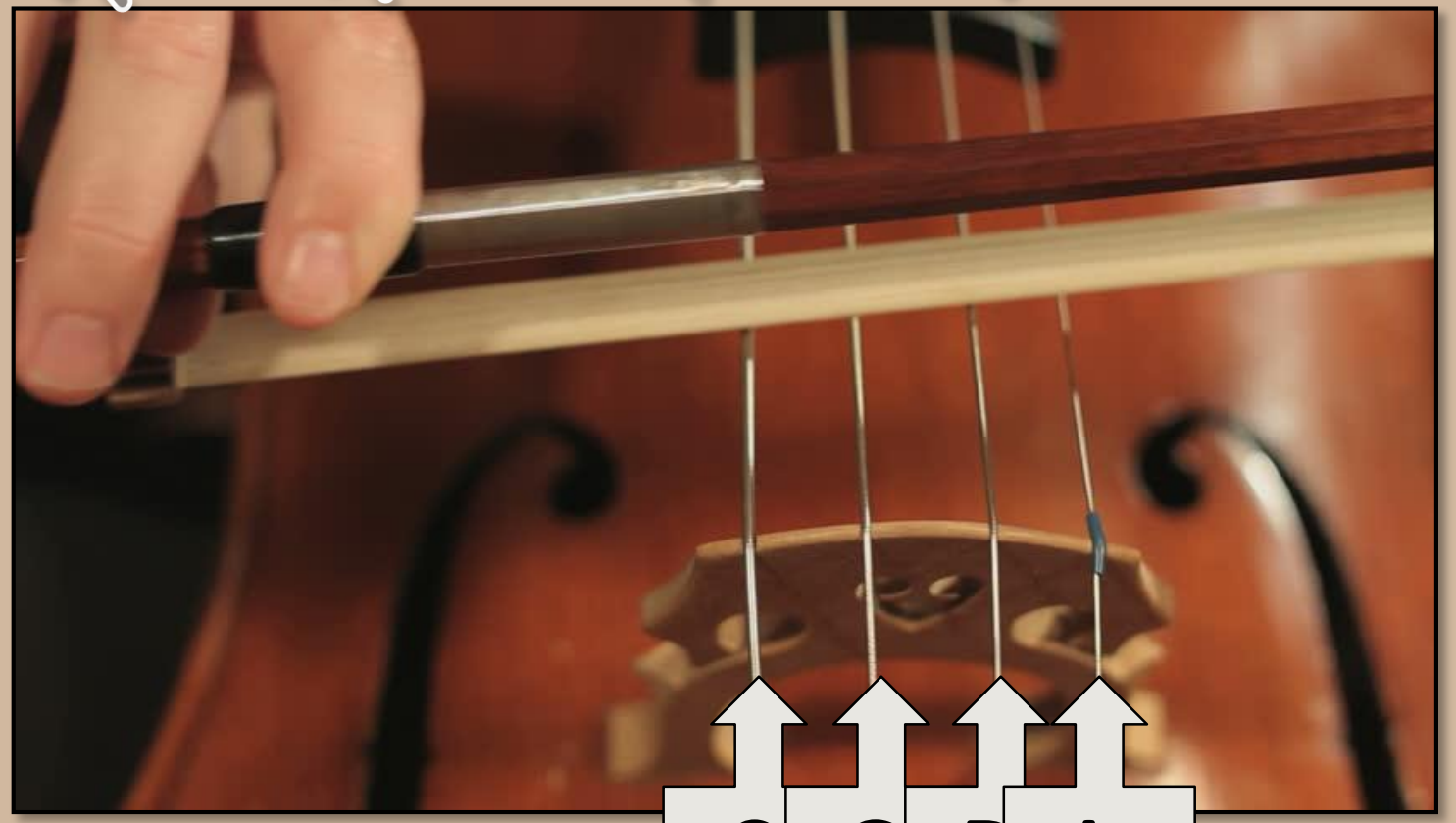
Tenor Trombone

Violin (G String)
Plucked

Violin (G String)
Bowed

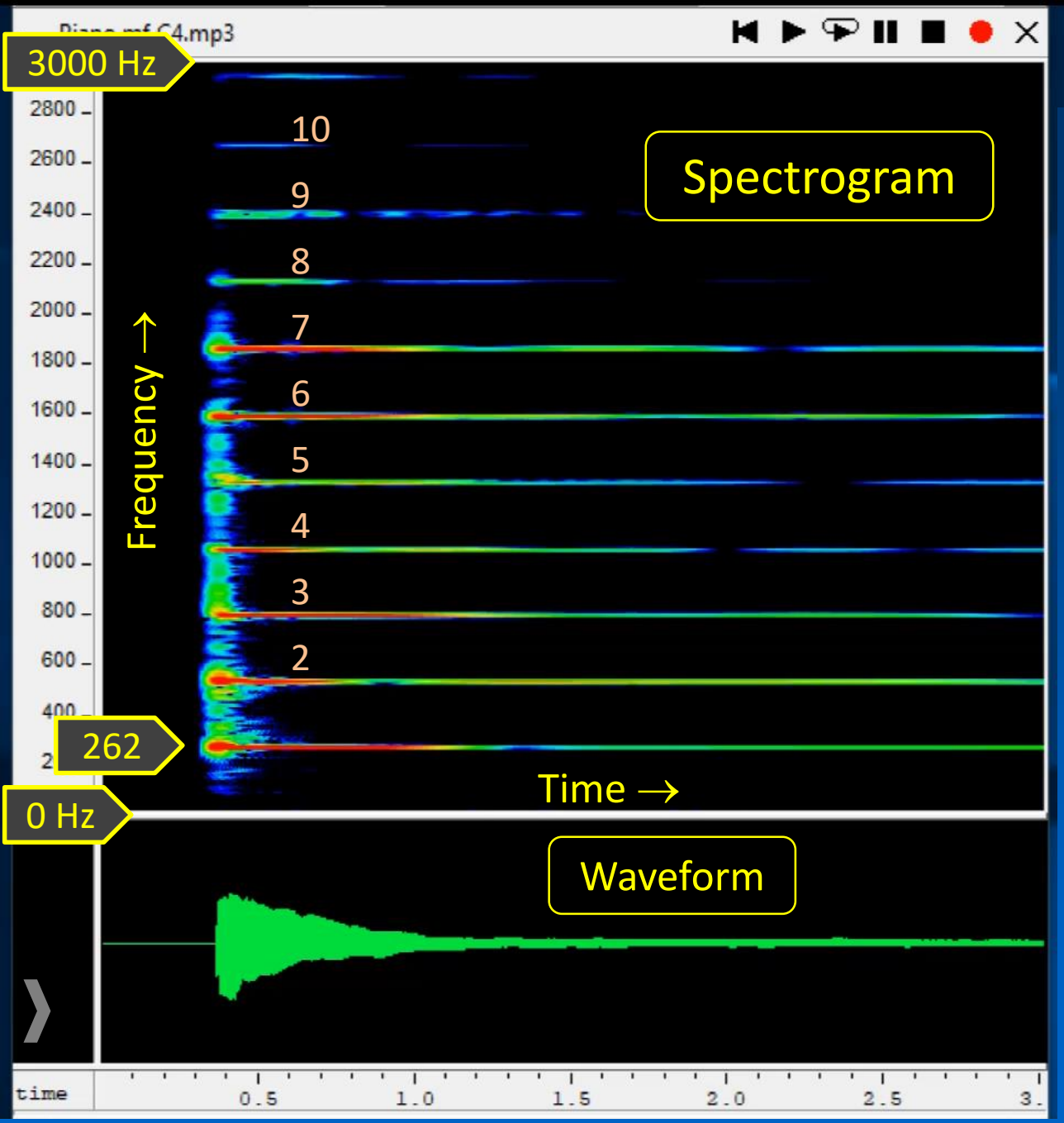
Timbre : Even for one instrument Timbre can vary

Cello



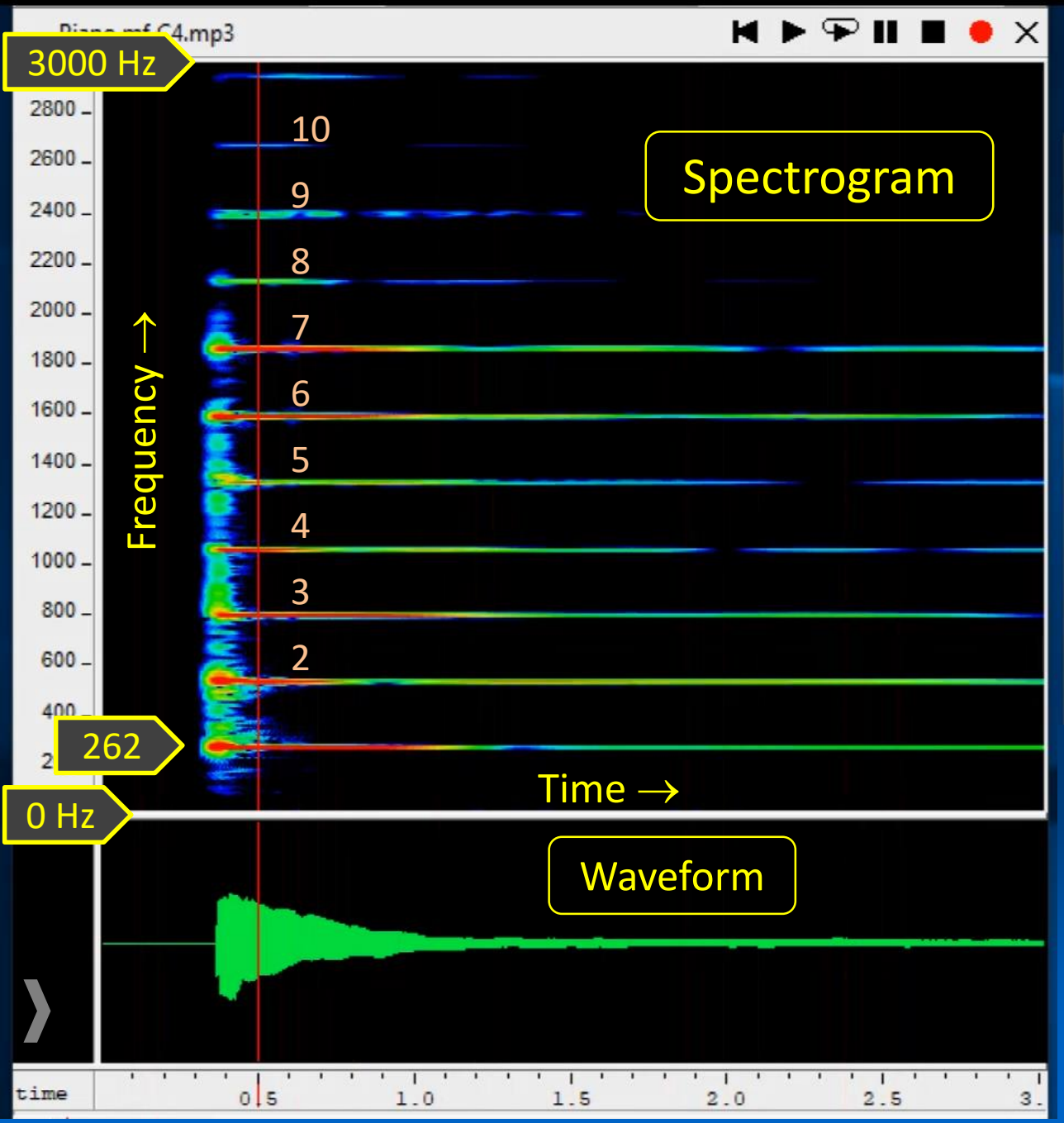
C4 (262 Hz) Played on Different Strings

What’s going on here?

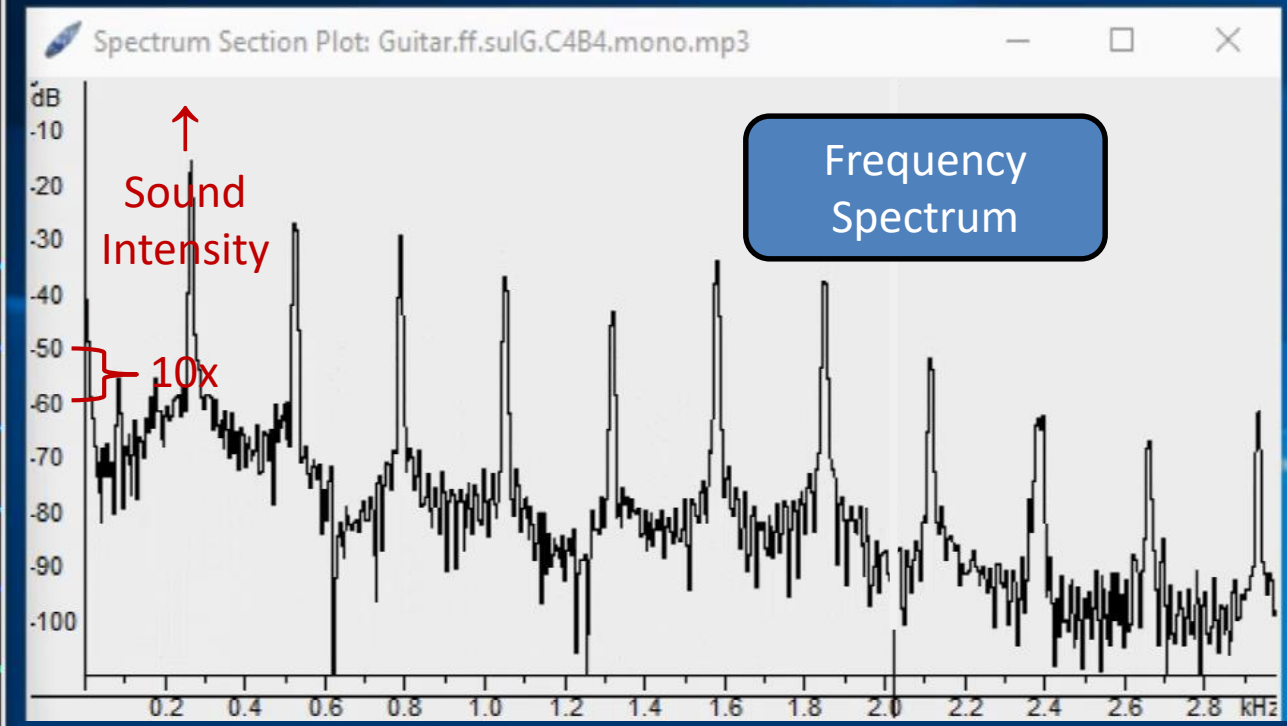


Piano C4 262 Hz

Visualizing a note
to understand Timbre

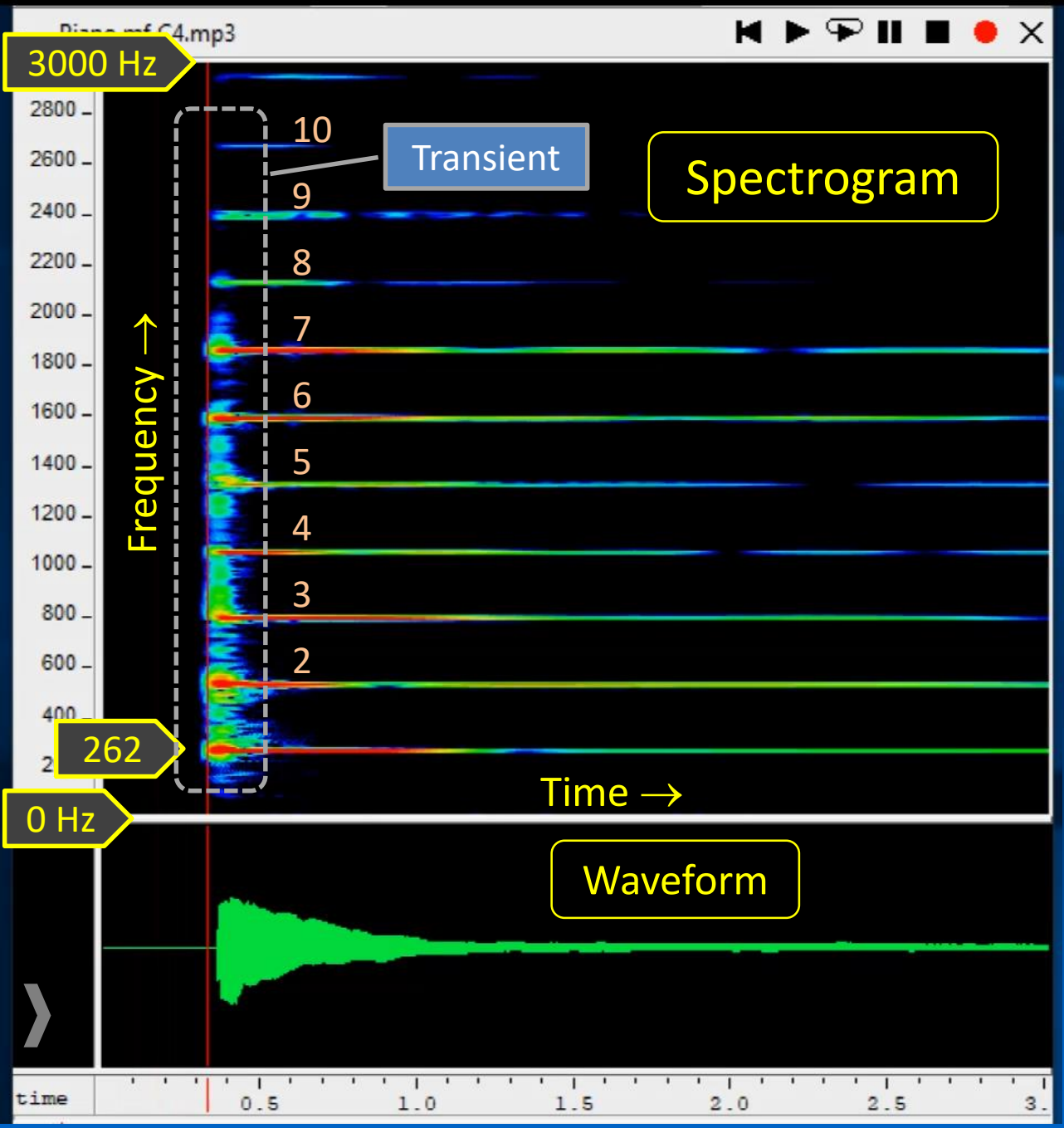


Piano C4 262 Hz

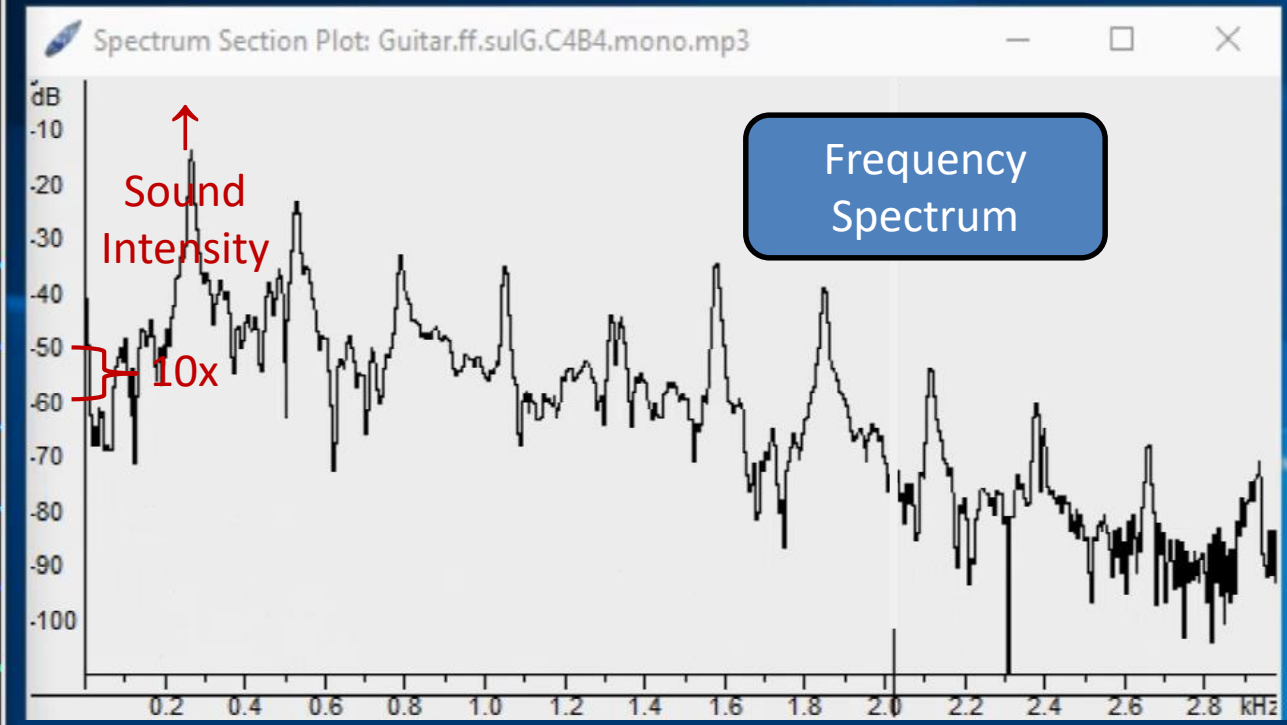


Frequency →

Visualizing a note
to understand Timbre



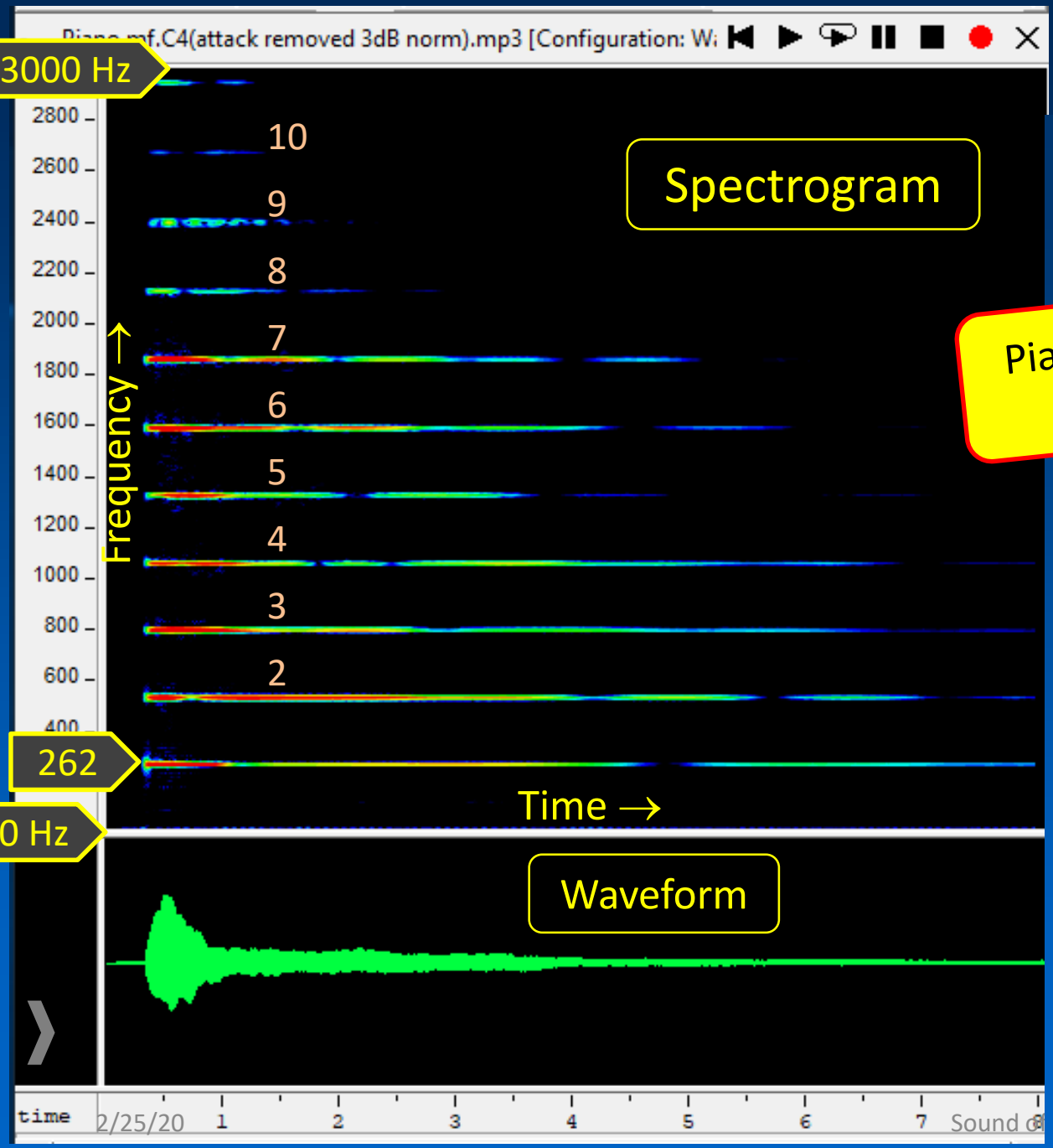
Piano C4 262 Hz



Frequency →

Visualizing a note to understand Timbre: The Attack

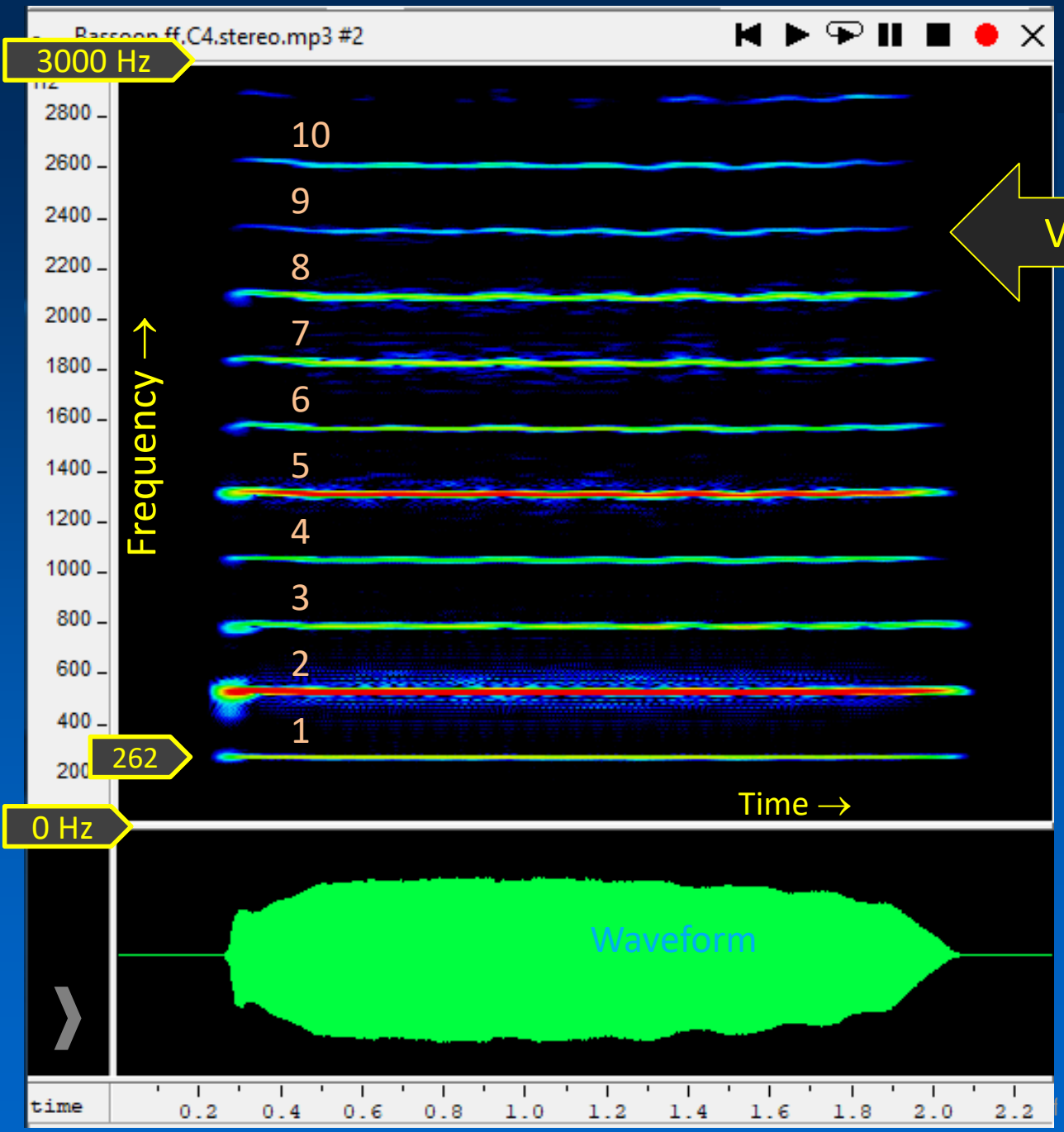
Piano C4 262 Hz



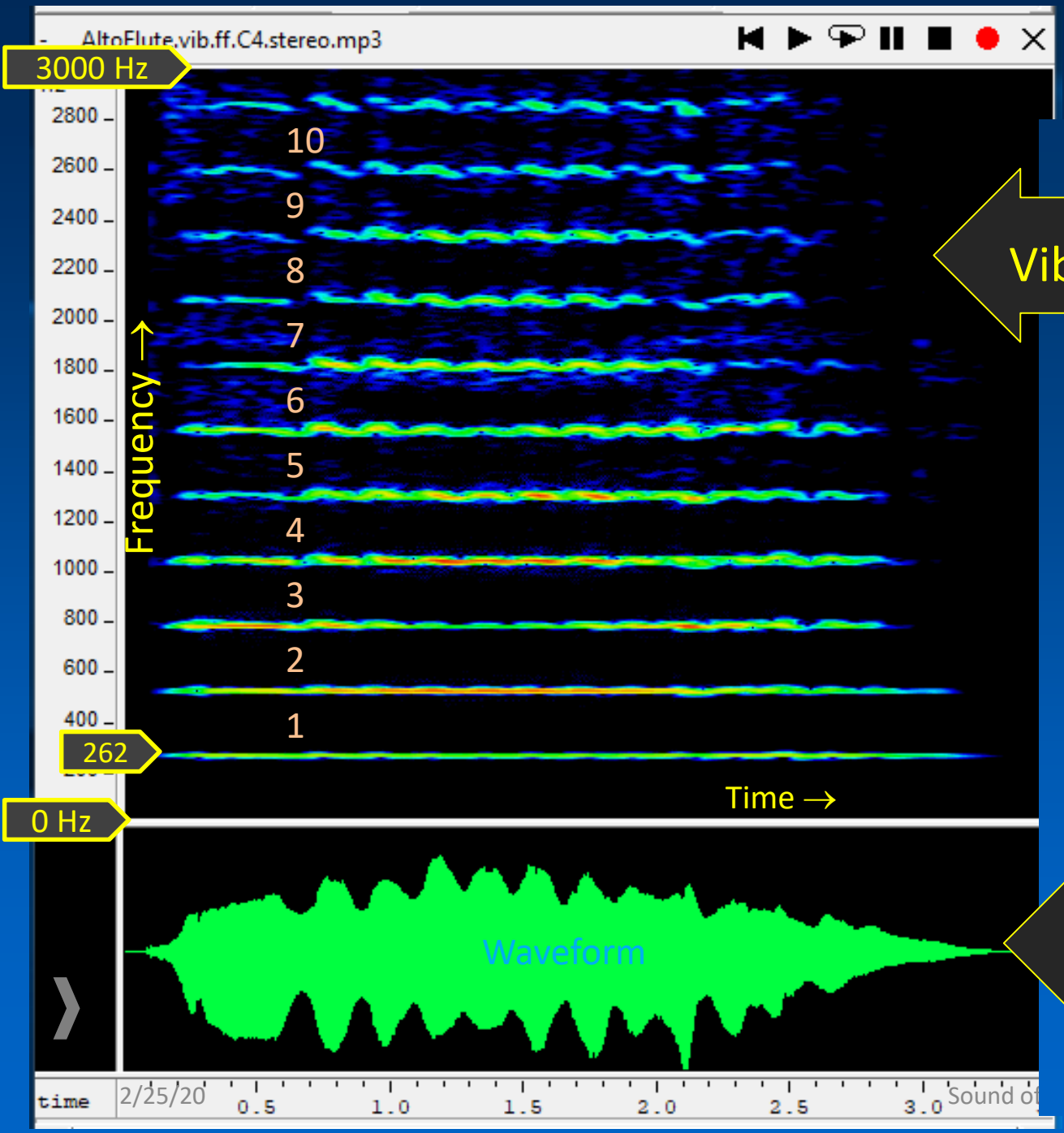
Piano C4 with "Hammer" Attack Removed

Visualizing a note to understand Timbre: The Attack removed

Bassoon C4 262 Hz



Visualizing a note
to understand Timbre:
Steady Tone

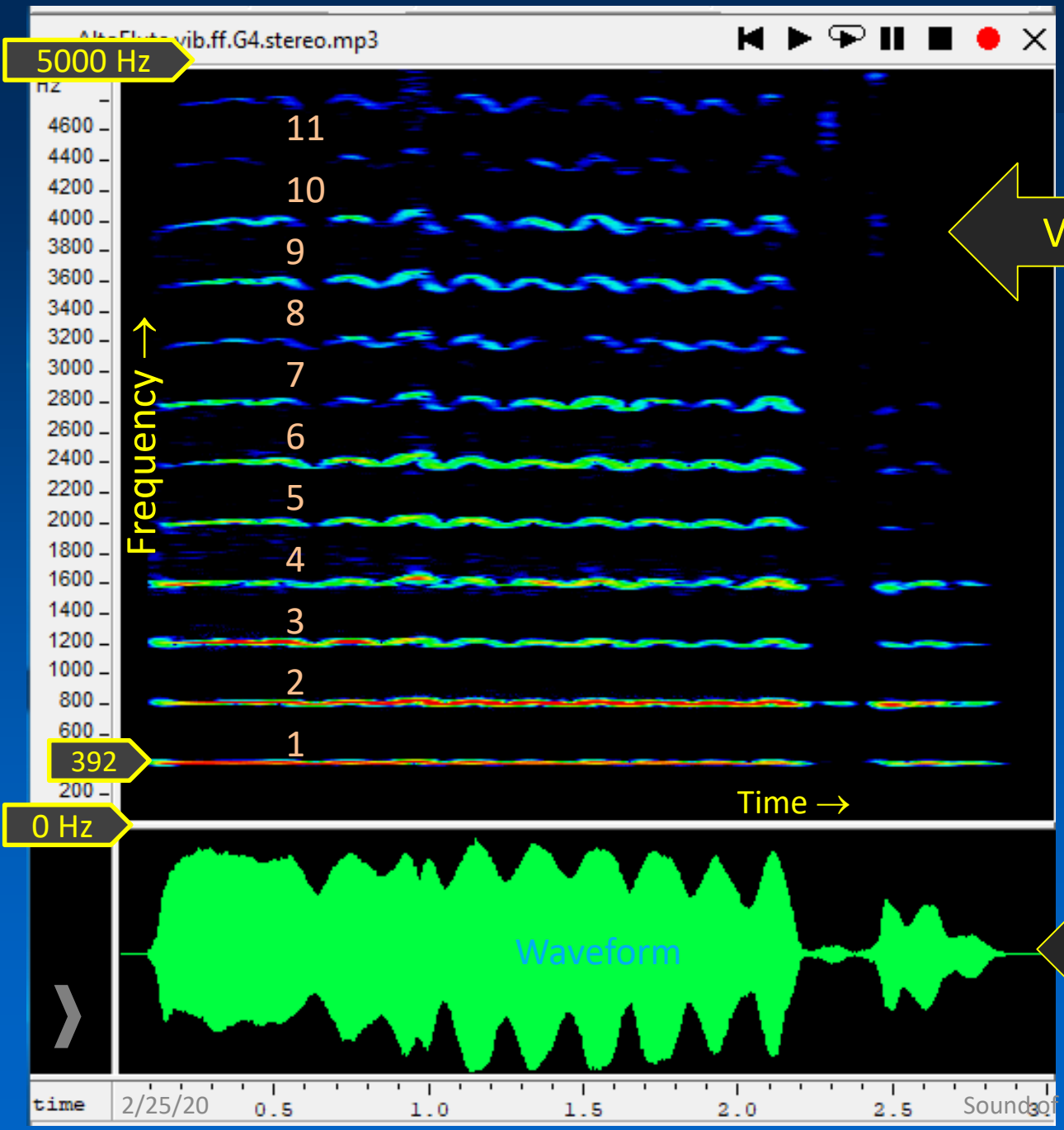


Alto Flute C4 262 Hz

Vibrato: f ↓↑

Visualizing a note
to understand Timbre:
Vibrato and Tremolo

Tremolo: Loudness ↓↑



Vibrato

Tremolo

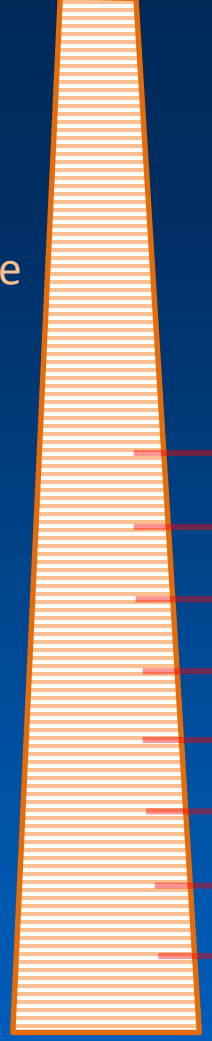
Alto Flute G4 392 Hz

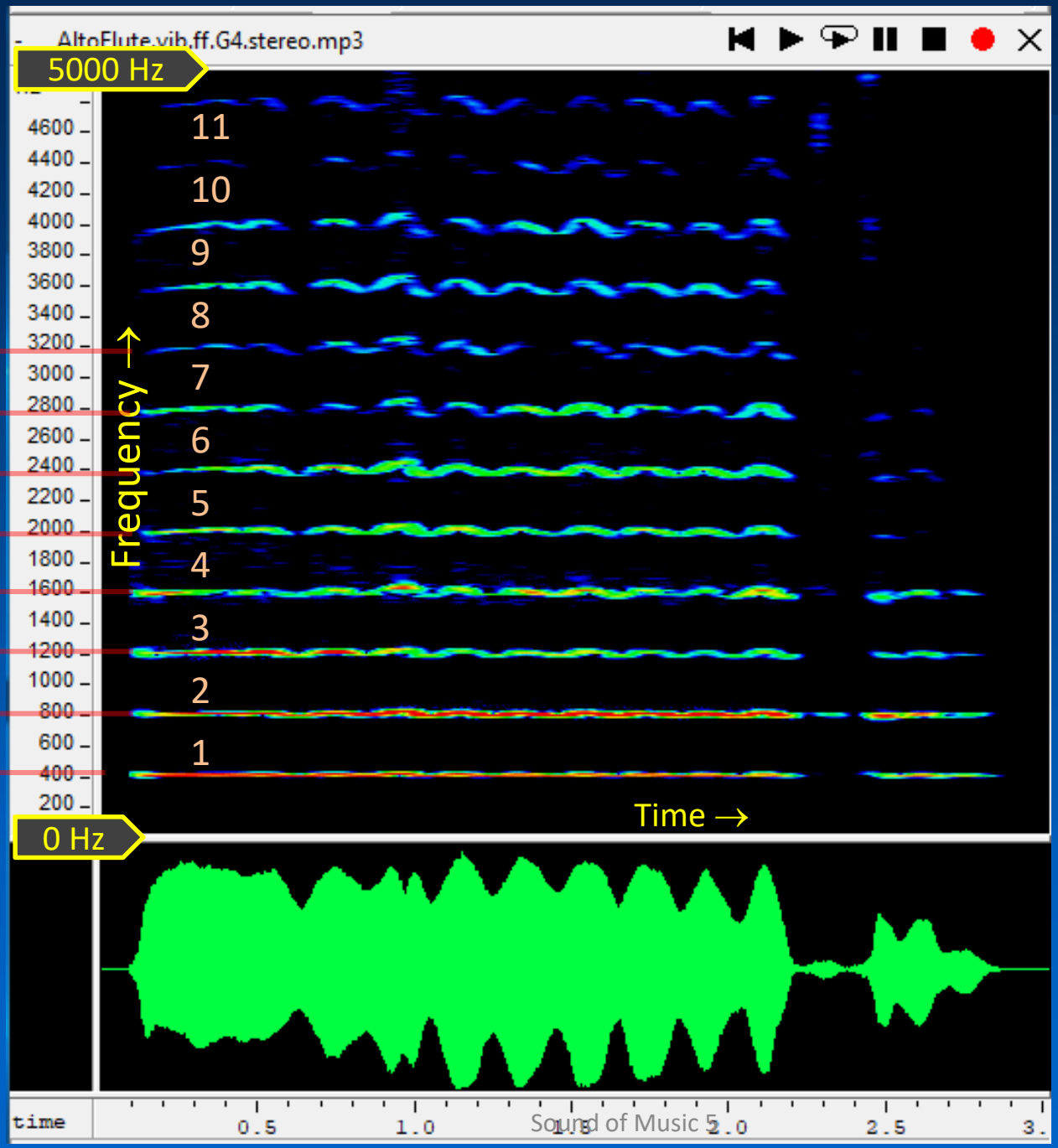
Higher Note

Visualizing a note
to understand Timbre:
Vibrato and Tremolo

Alto Flute G4

Basilar Membrane

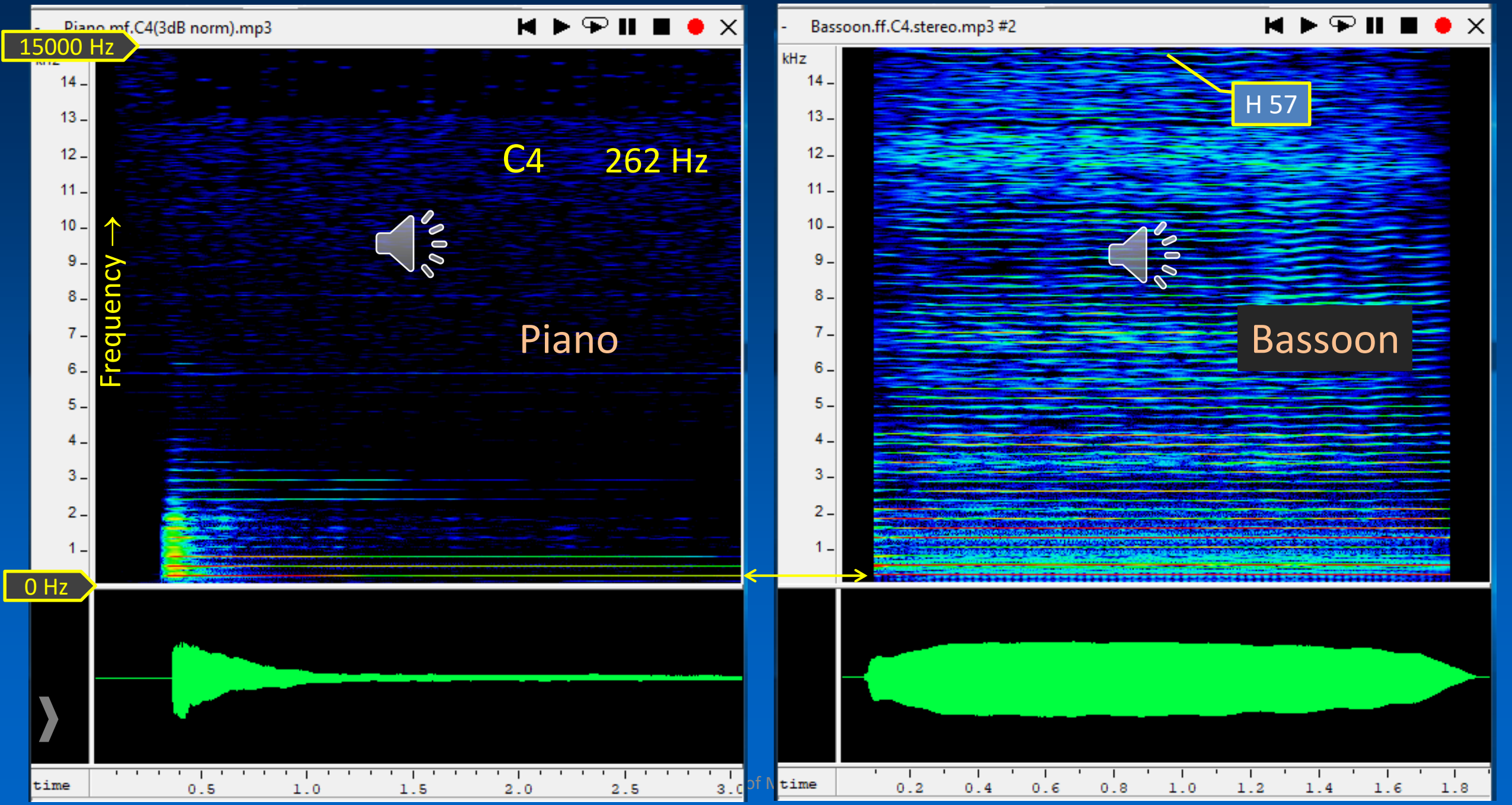




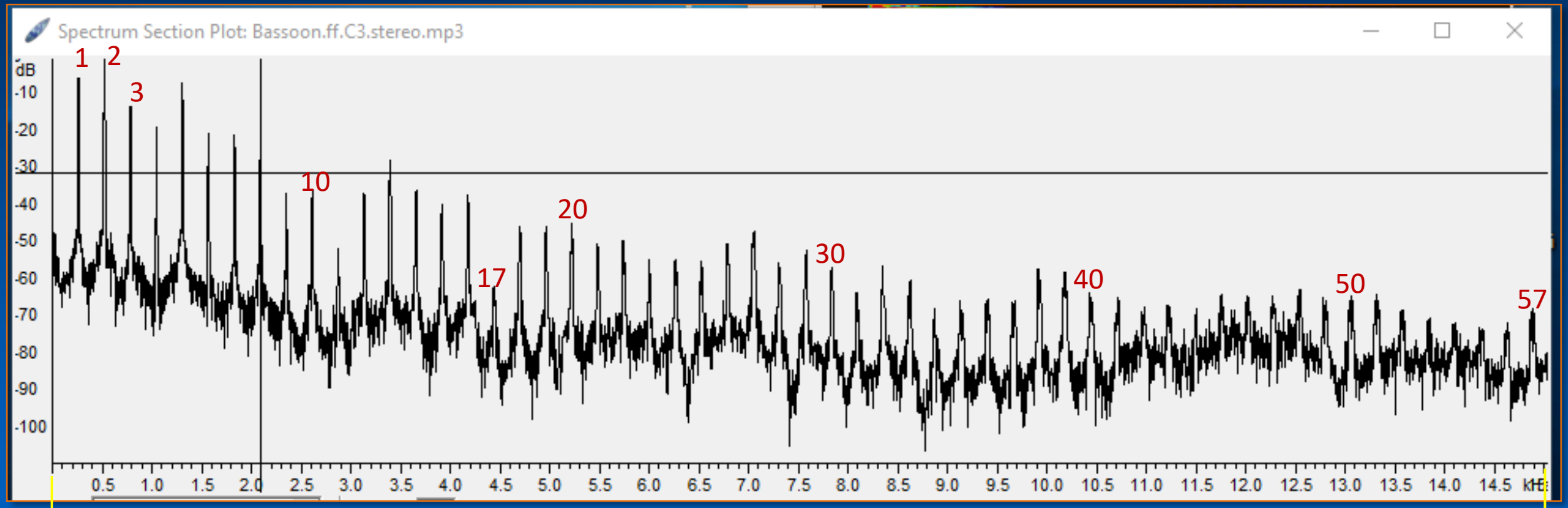
In all cases, different harmonics fall on different parts of the Basilar Membrane…

but not always on different Critical Bands

Back to Piano *vs.* Bassoon (C4 262 Hz)


Piano mf.C4(3dB norm).mp3
15000 Hz
C4
262 Hz
Frequency →
Piano
0 Hz
time
0.5
1.0
1.5
2.0
2.5
Bassoon.ff.C4.stereo.mp3 #2
kHz
H 57
Bassoon
time
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8

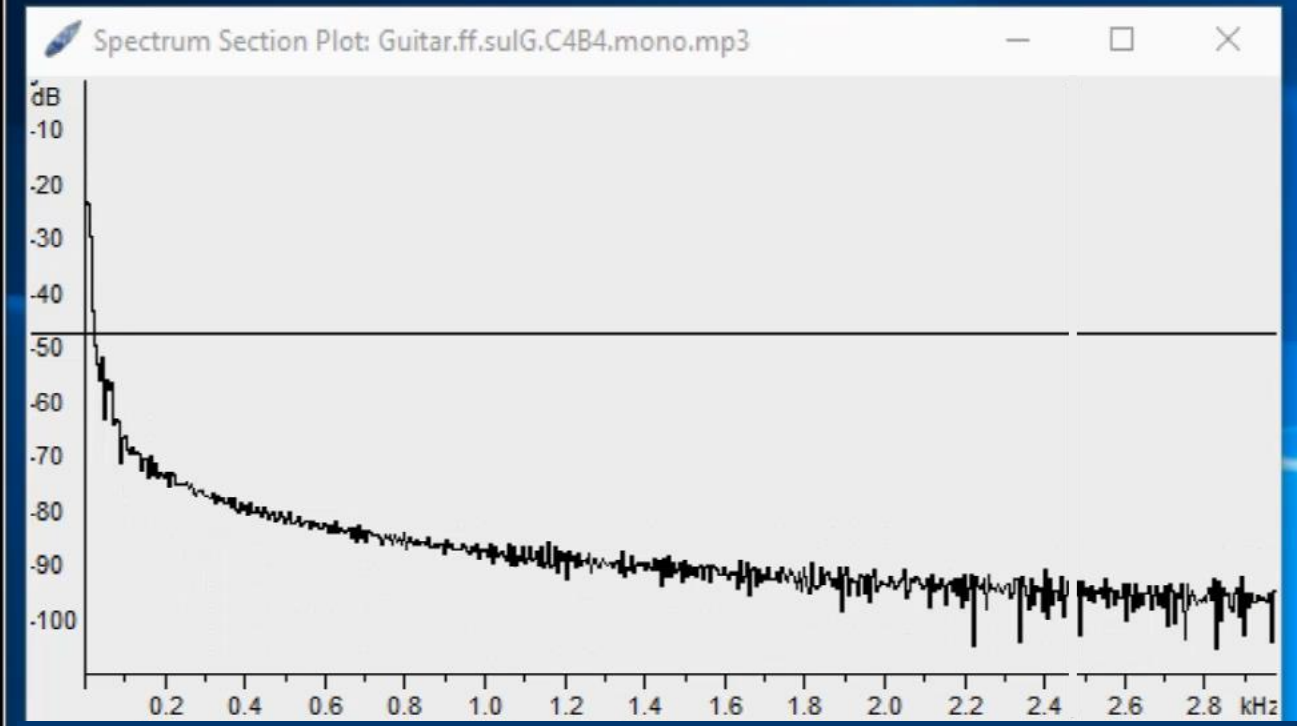
Bassoon C4 Spectrum 0 to 15 kHz



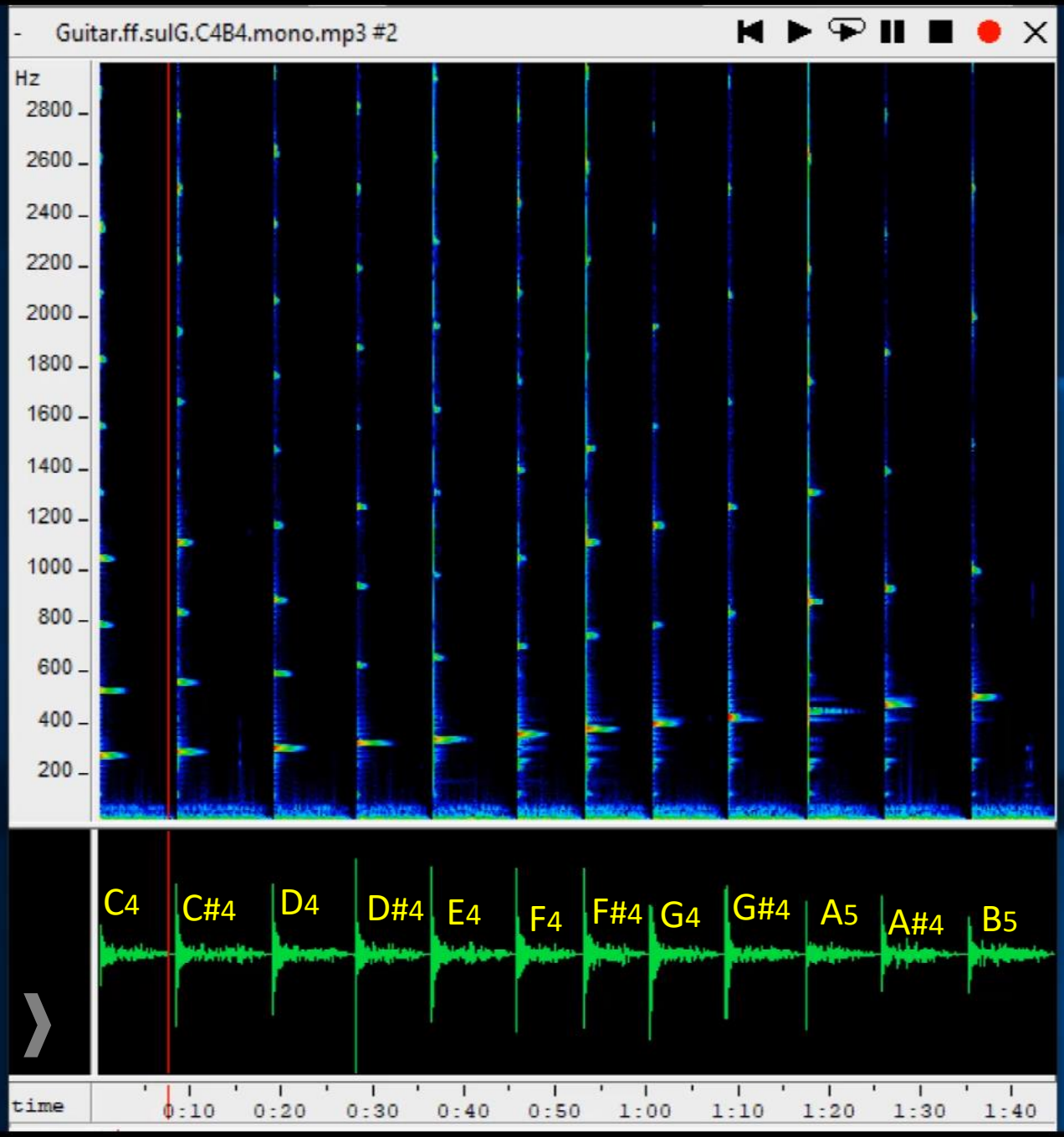
0 **Frequency →** 15 kHz

Guitar Scale C4 to B4 *(G String)*

262 Hz 494 Hz



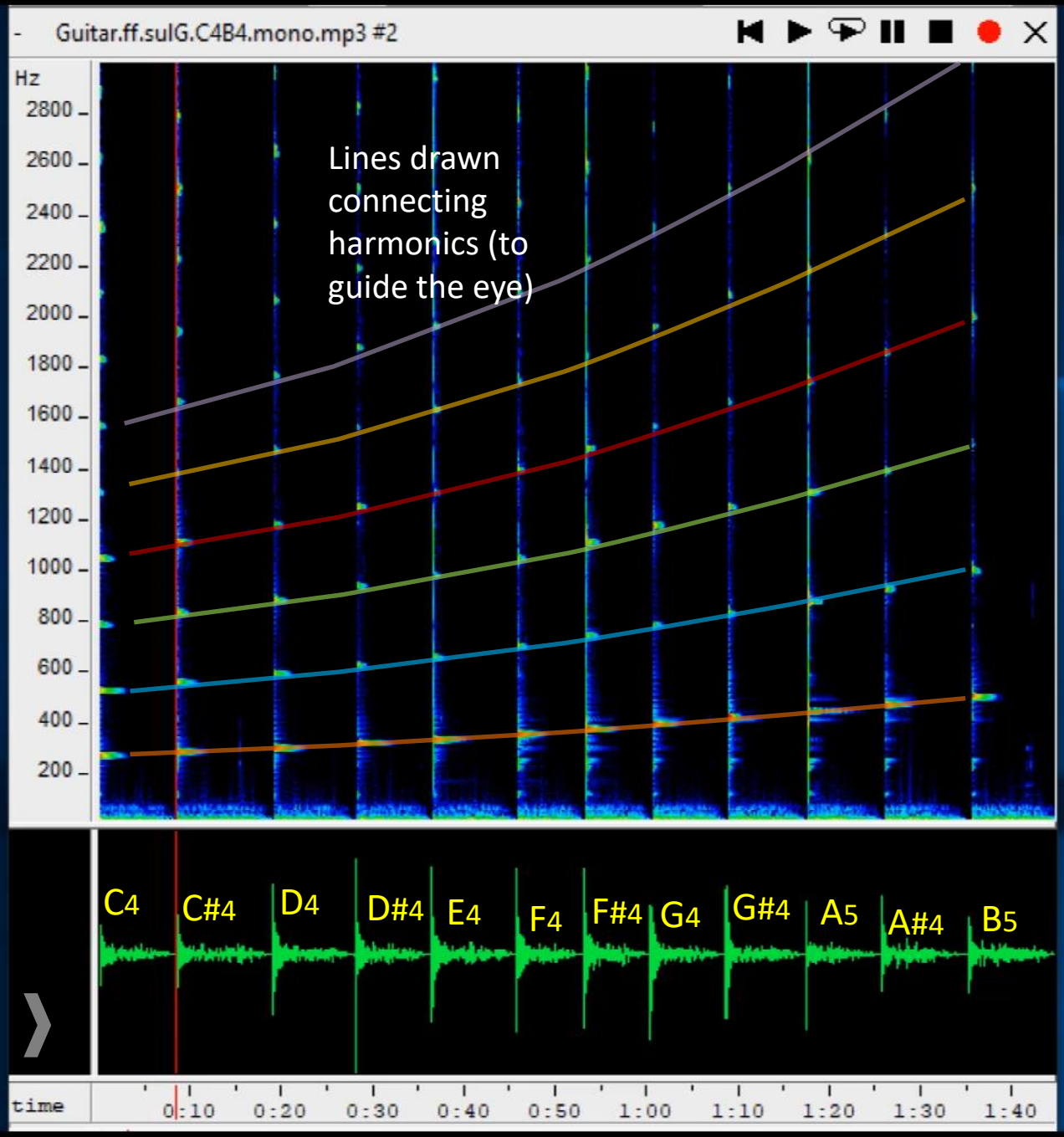
Frequency →

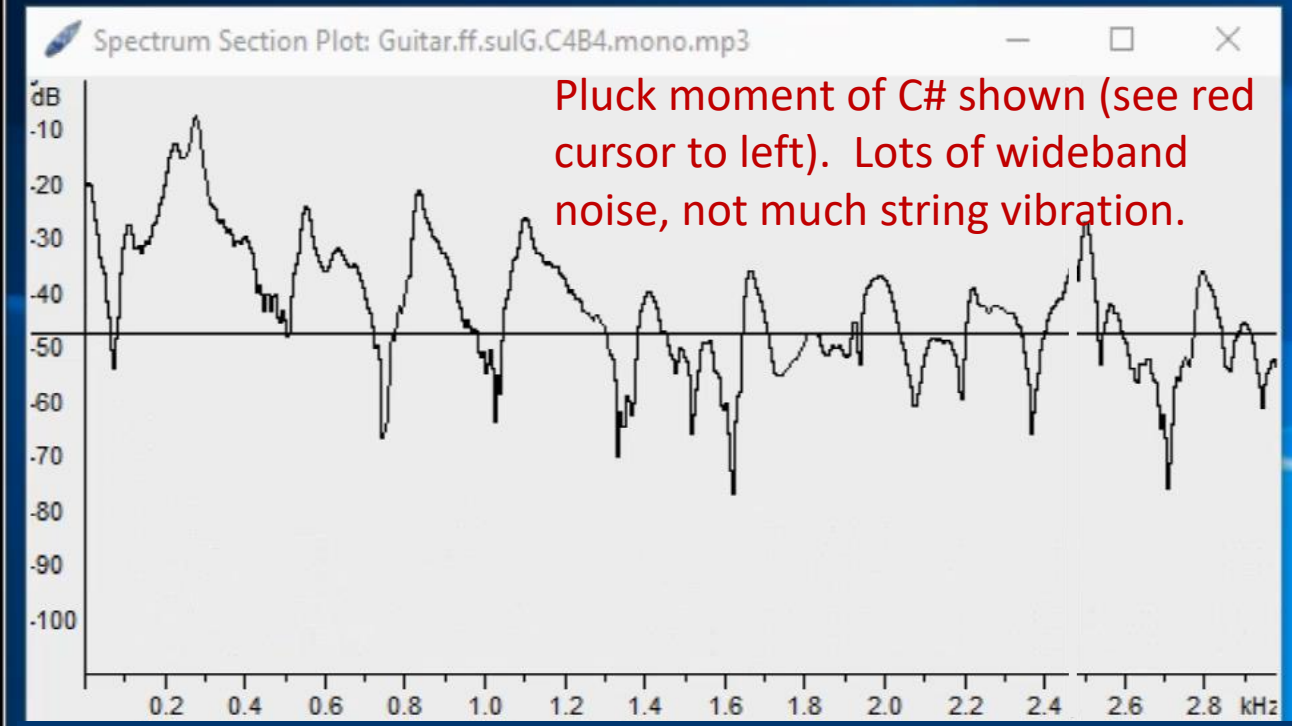


High Harmonics Drop Off Faster

Guitar Scale C4 to B4 *(G String)*

262 Hz 494 Hz



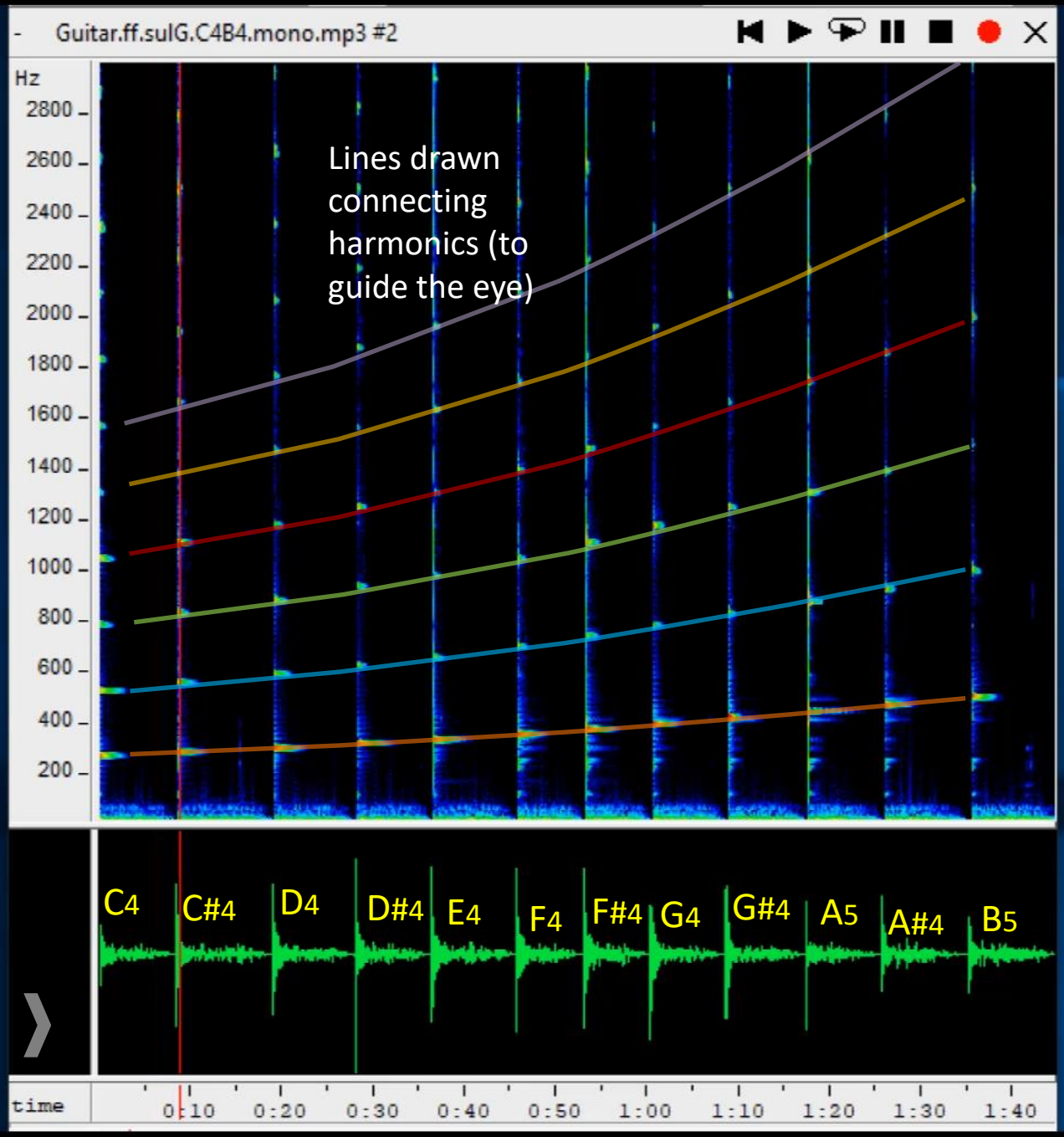


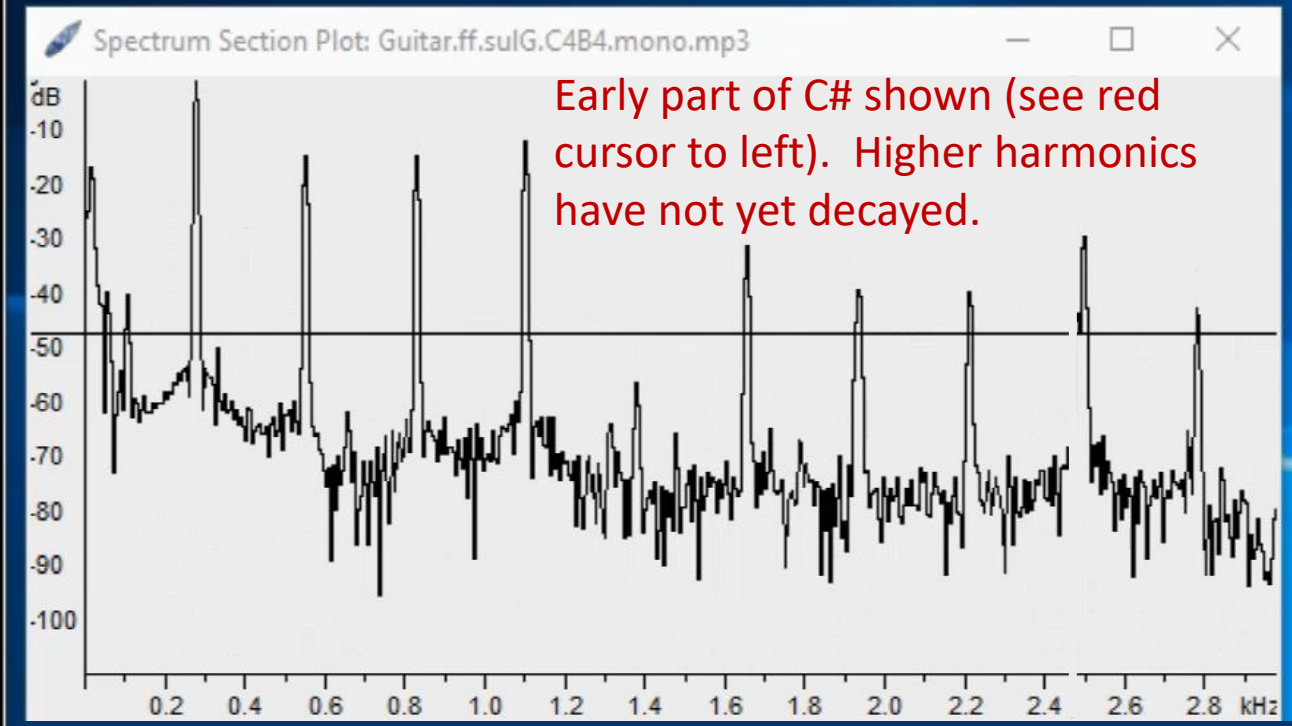
Frequency →

High Harmonics Drop Off Faster

Guitar Scale C4 to B4 *(G String)*

262 Hz 494 Hz



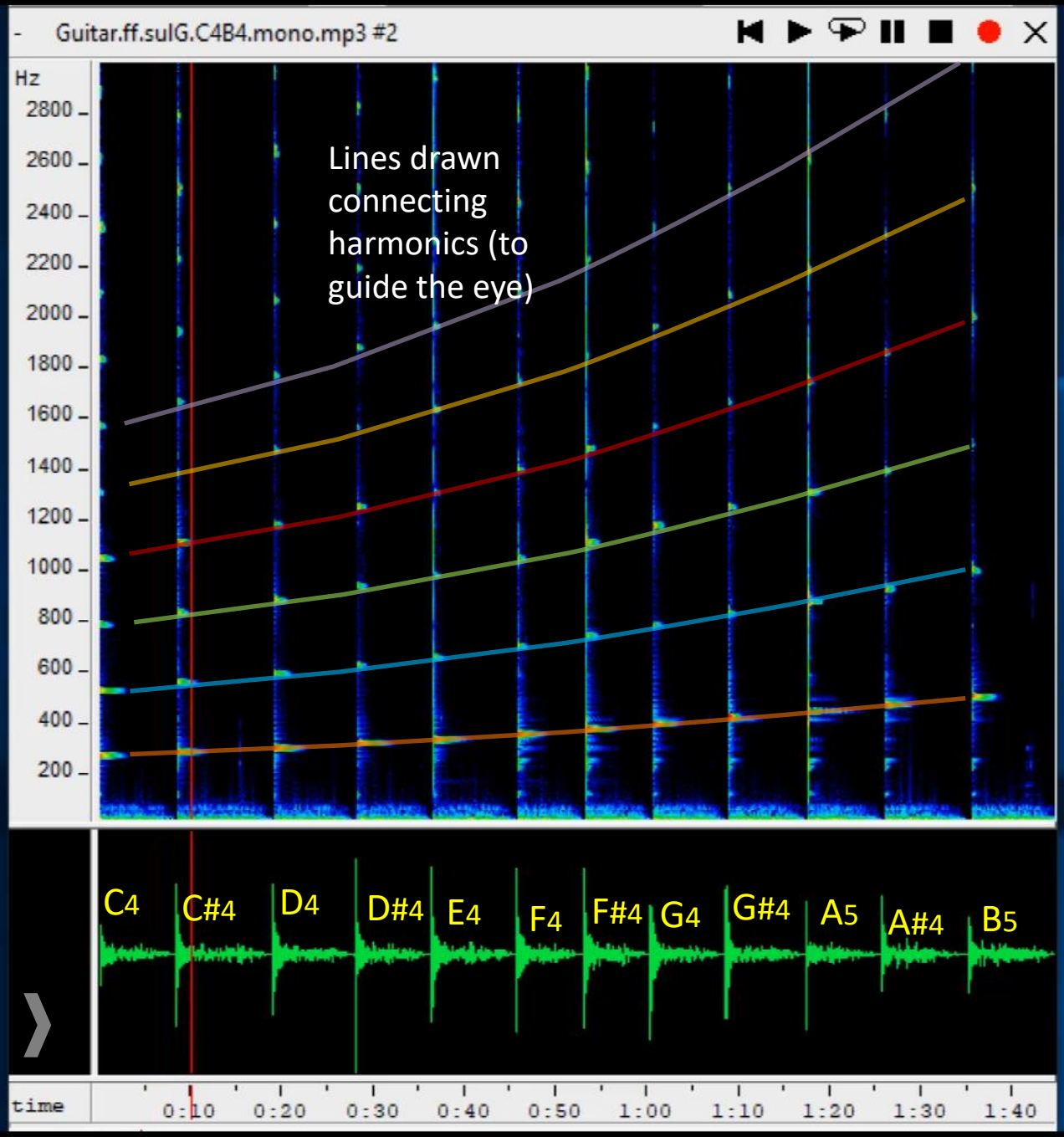


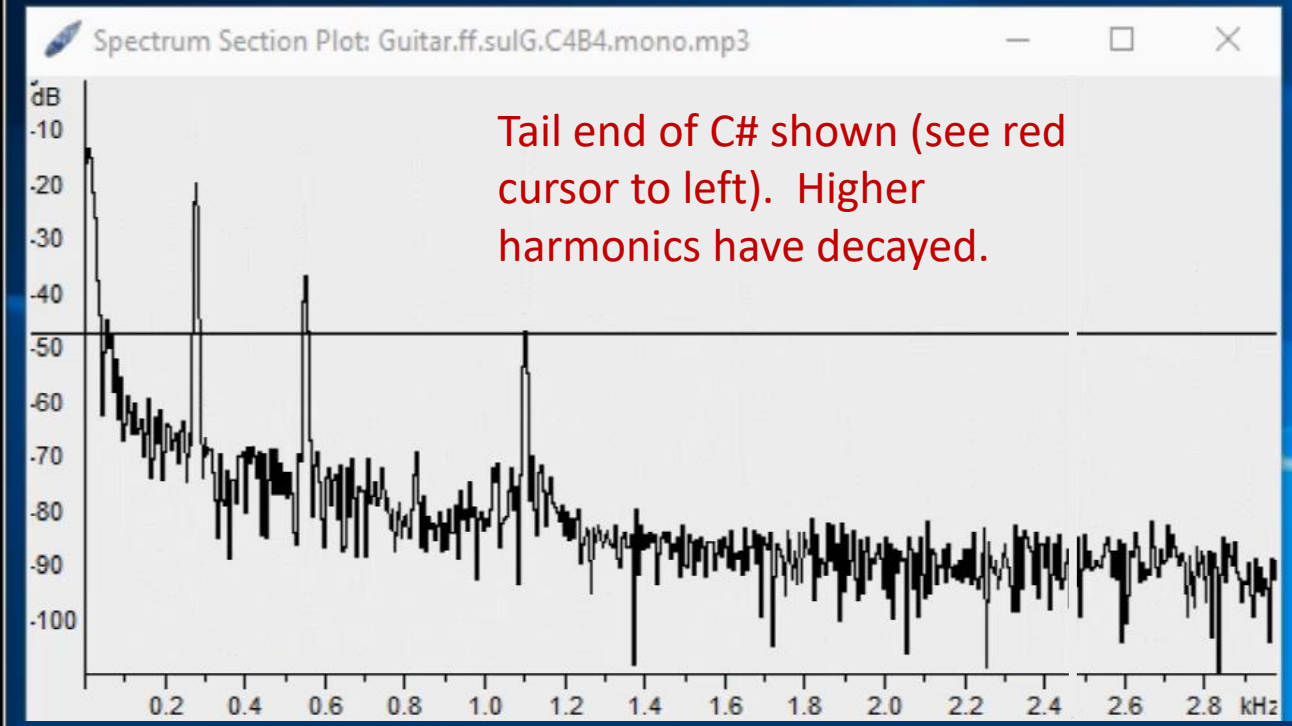
Frequency →

High Harmonics Drop Off Faster

Guitar Scale C4 to B4 *(G String)*

262 Hz 494 Hz





Frequency →

High Harmonics Drop Off Faster

So What Determines Timbre of a Note?

- Harmonic intensity pattern
- The decay of the Fundamental and Harmonics
  - or lack of decay
- The Attack
  - rate of onset
  - accompanying noise (Transients)
- Frequency variation / vibrato
- Amplitude variation / tremolo [The Envelope]
- Non-harmonic partials

Strings

Mesopotamian Strings: Golden Lyre of Ur

- From “Royal Tombs” at Ur, Sumeria (~2600 BC)
- Excavated ~1929
  - British Museum/U Penn Expedition
  - Led by Leonard Woolley
- 4 Excellent Lyres found
- Best : **The Golden Lyre**
  Iraq Museum, Baghdad (Restored)

3 Lyres as excavated

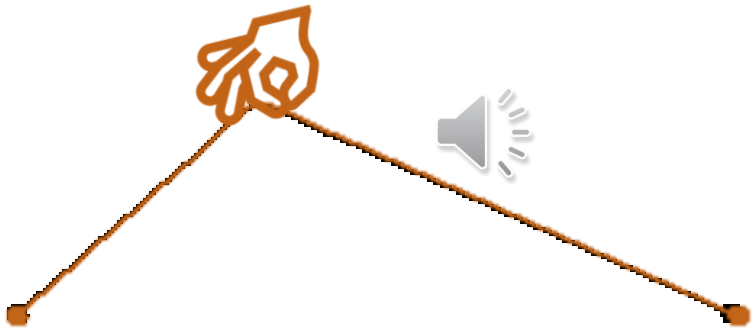

Woolley with a plaster stabilized lyre

Strings

String Instruments

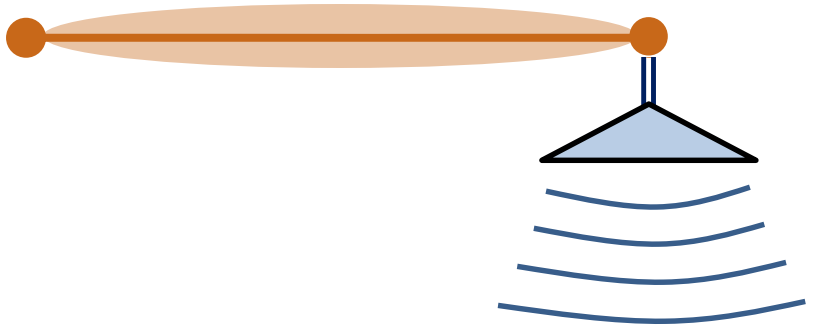
Three main problems:

1. Excitation EASY
   - How to get the string vibrating



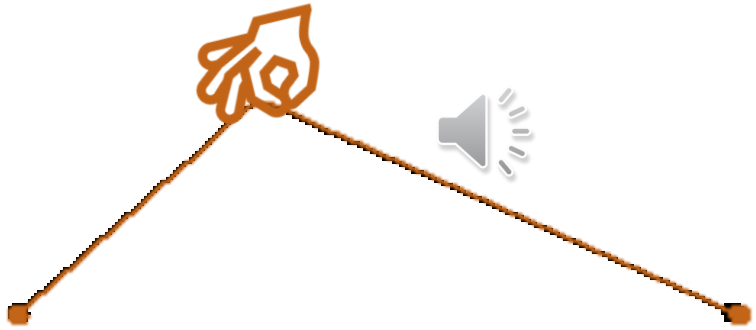
2. Frequency Control EASY
   - Playing desired notes

3. Getting Sound Out HARD
   - Coupling string vibrations to sound waves



Strings

Exciting the String: Plucking

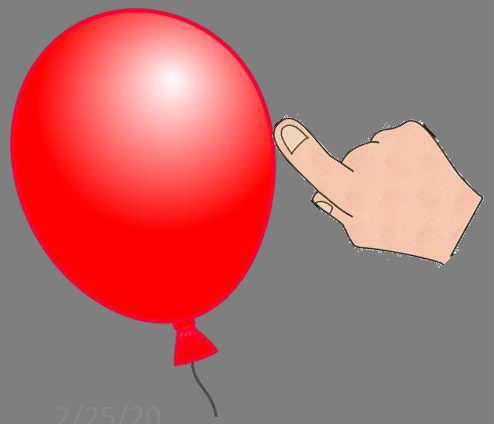


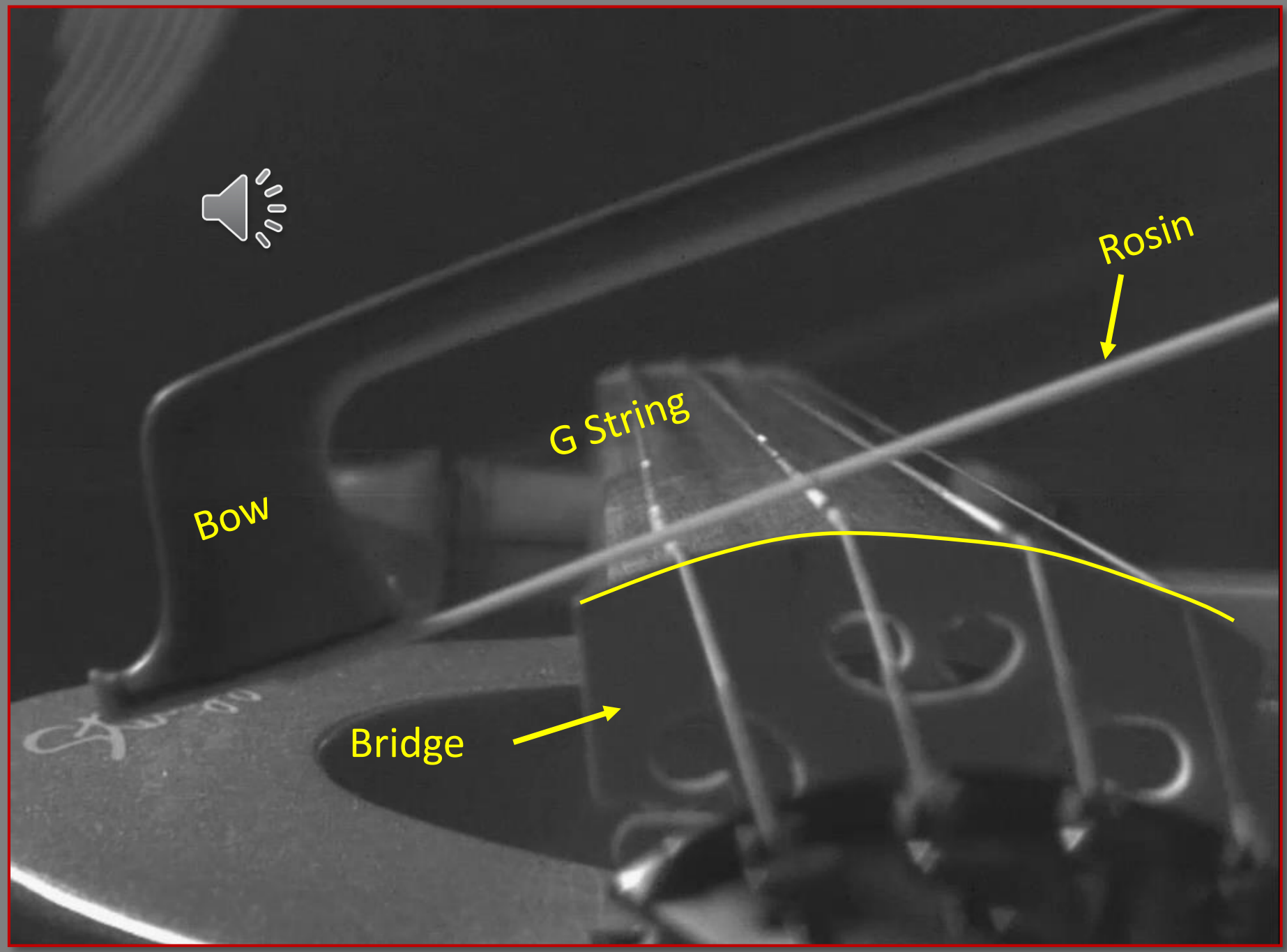
Bass Guitar
Cruickshank, University of St. Andrews

Strings

Exciting the String: Bowing

Stick-Slip Friction



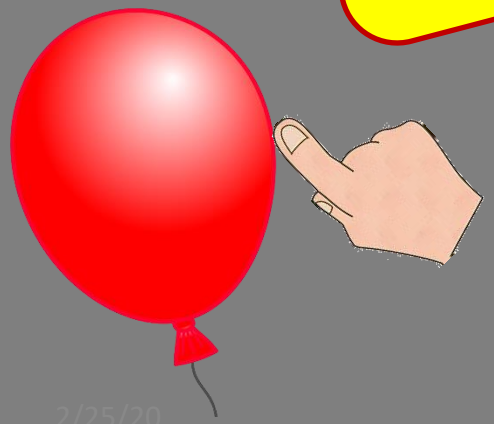


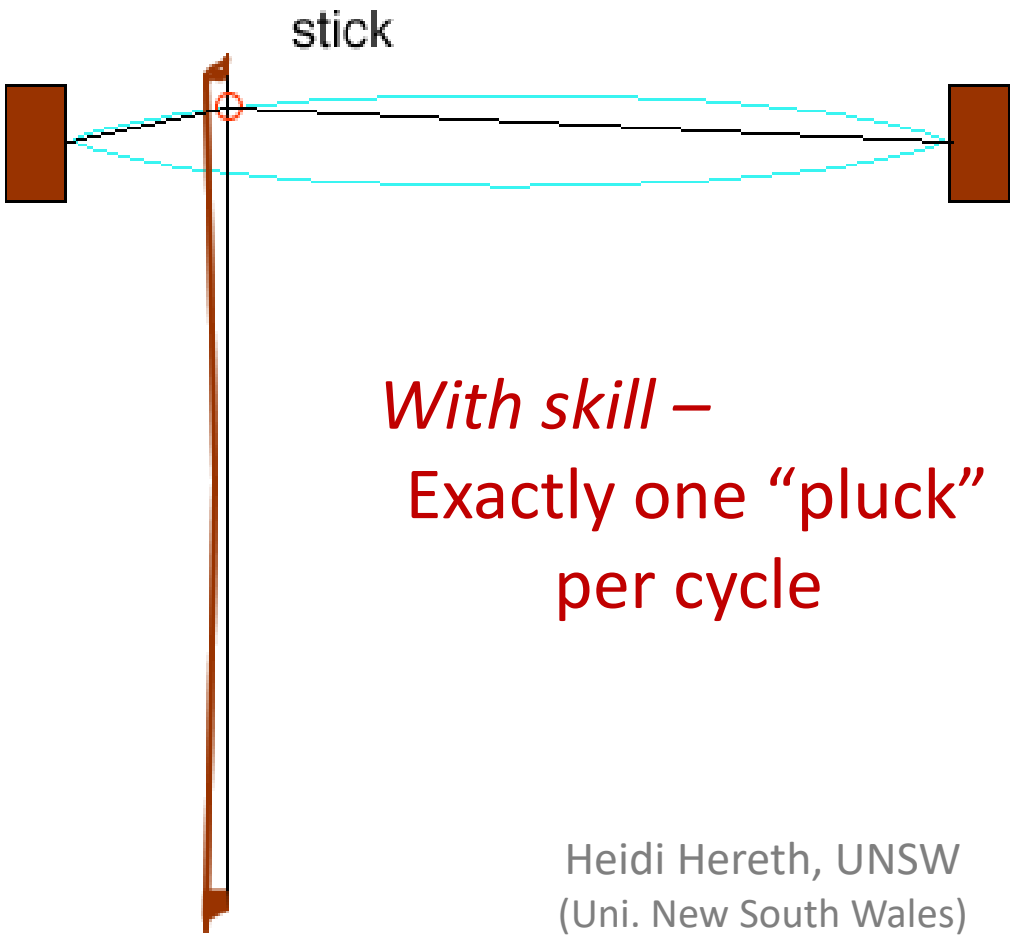
Strings

Exciting the String: Bowing

Stick-S
Frictio

Result:
High Harmonics have no time to decay.
Brilliant Timbre





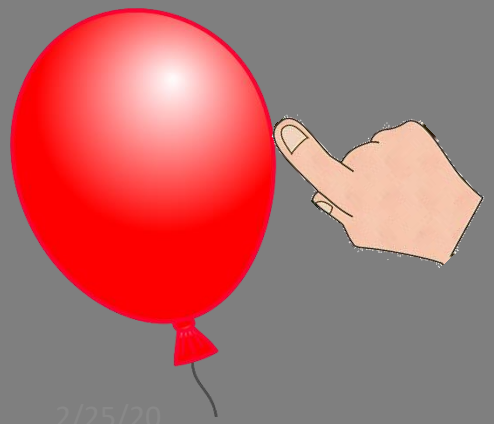
With skill –
Exactly one “pluck” per cycle

Heidi Hereth, UNSW
(Uni. New South Wales)

Strings

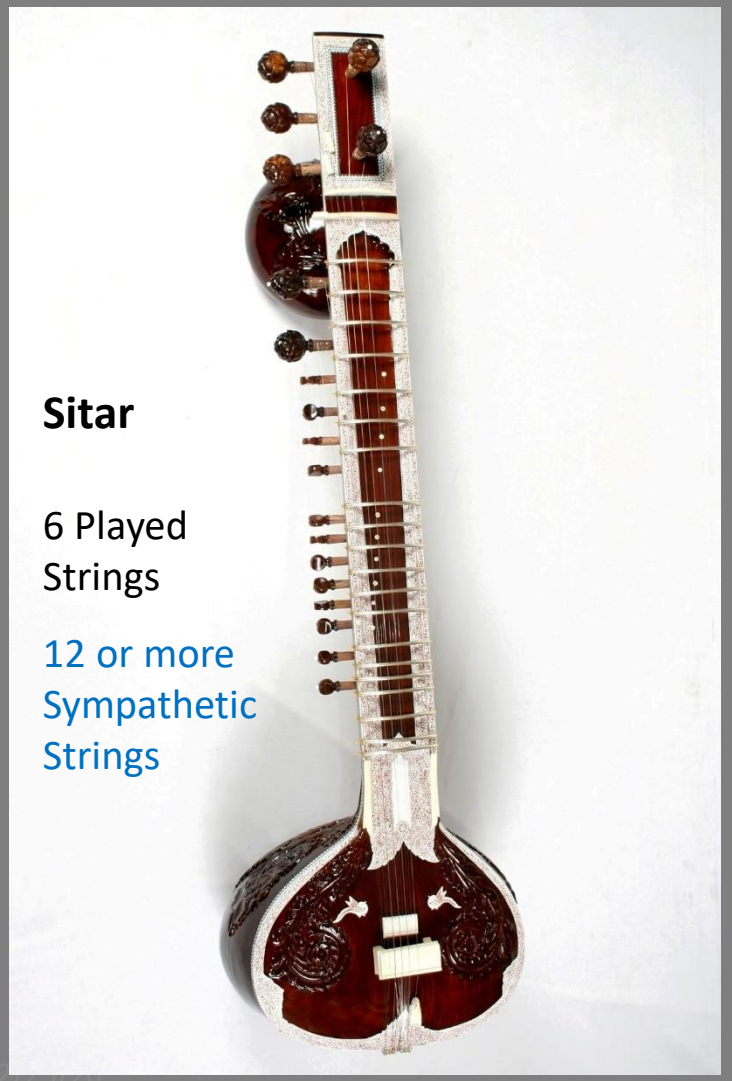
Exciting the String: Bowing

Stick-Slip Friction



Strings

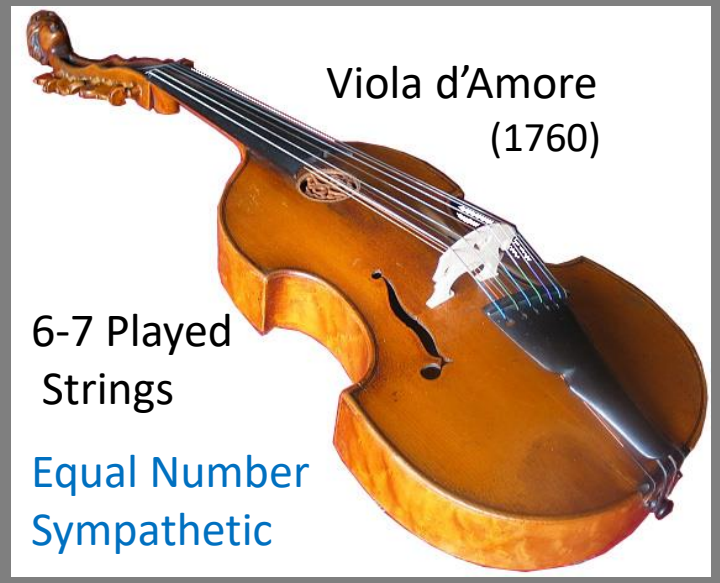
Exciting the Strings: Sympathetic Vibration



Sitar

6 Played Strings

12 or more Sympathetic Strings



Viola d'Amore (1760)

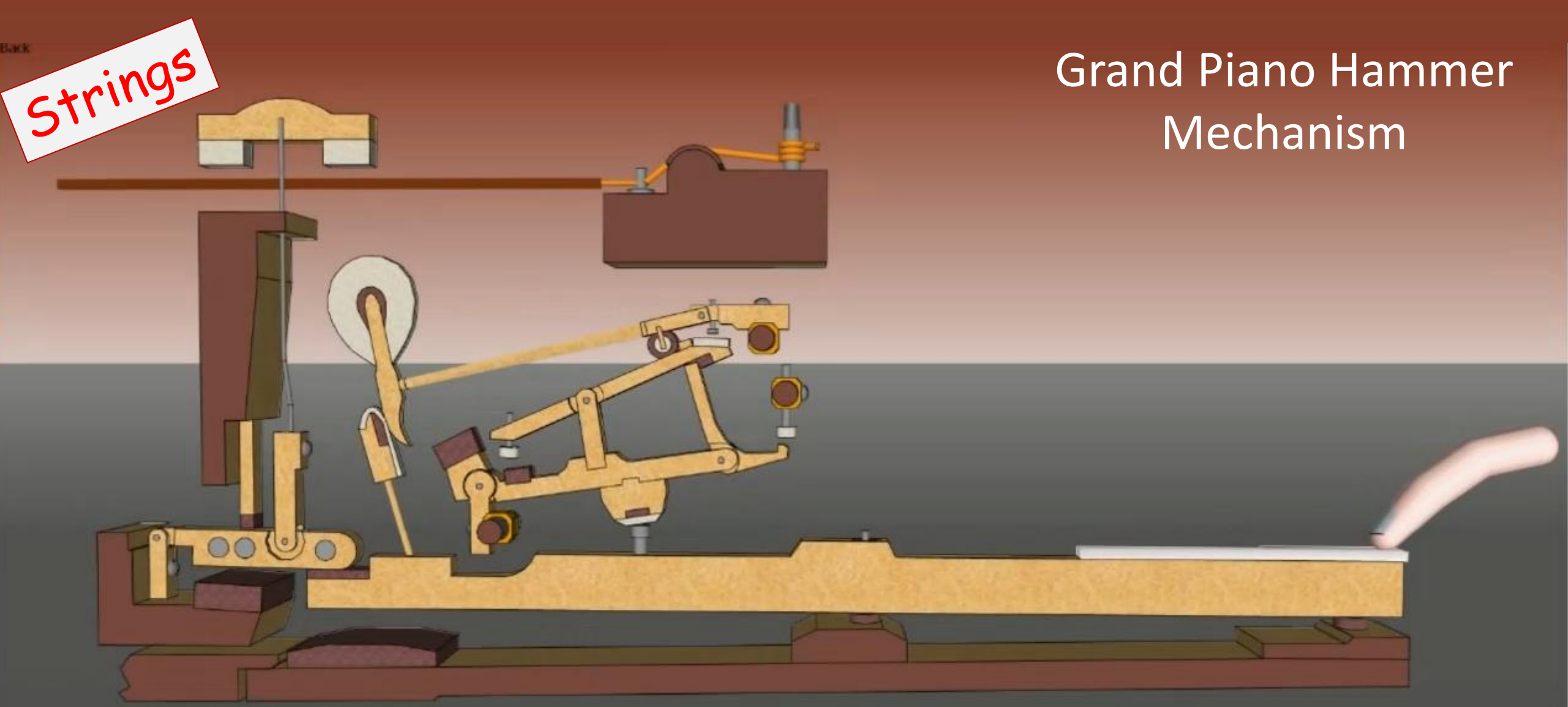
6-7 Played Strings

Equal Number Sympathetic

Aliquot Strings

Strings

Grand Piano Hammer Mechanism



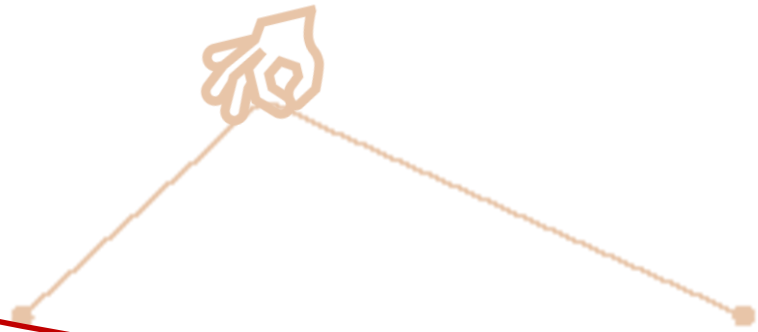
Animation: Hoe Ishetmogelijk (2014)
Music: Haydn Piano Sonata No. 30 D Major

Strings

String Instruments

Three main problems:

1. Excitation EASY
   - How to get the string vibrating

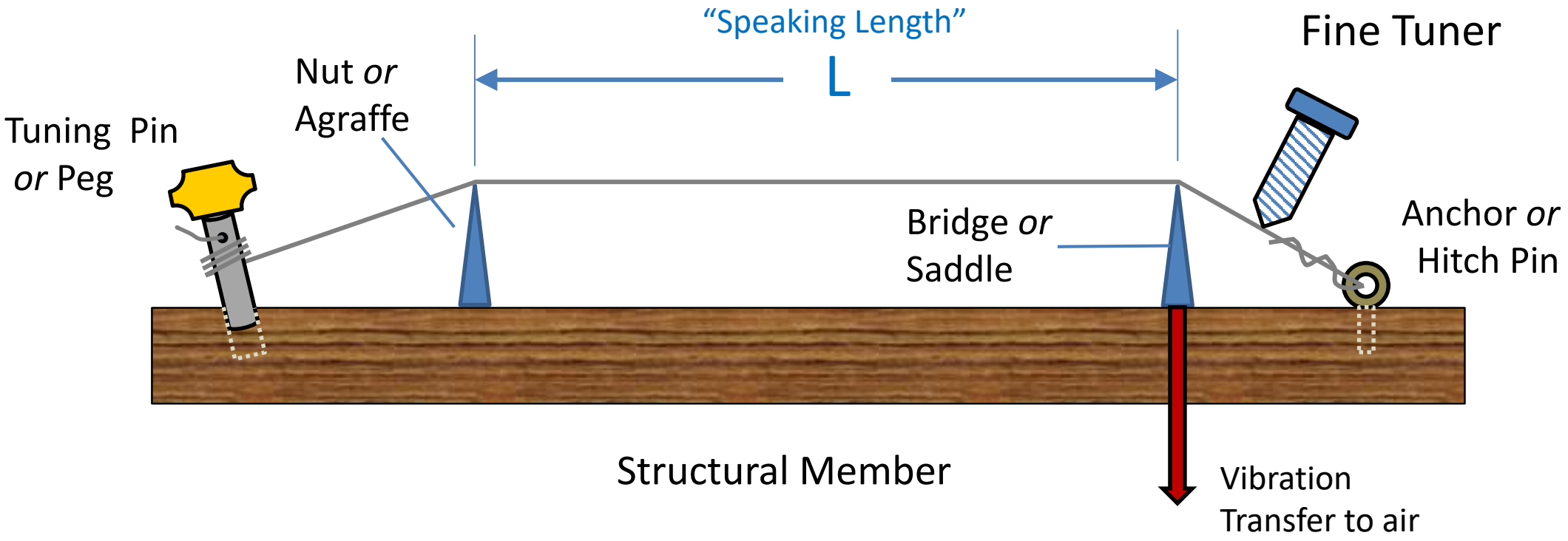


2. Frequency Control EASY
   - Playing desired notes

3. Getting Sound Out HARD
   - Coupling string vibrations to sound waves

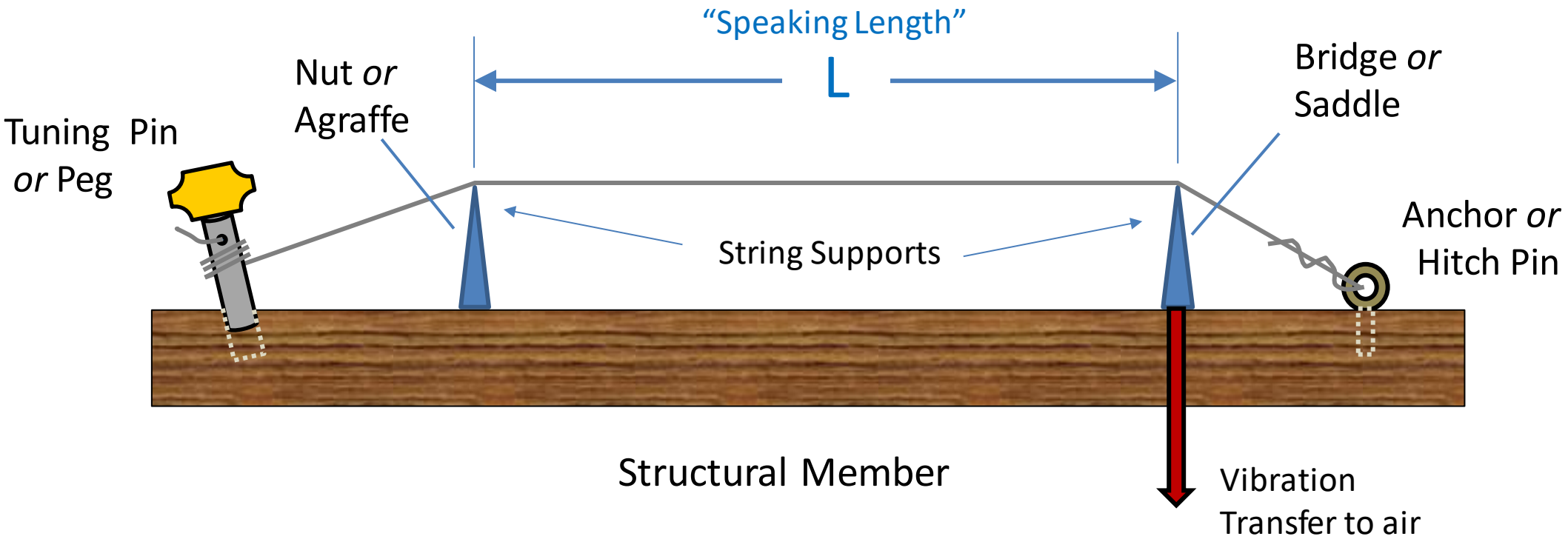
Strings

Generic String: Fixed Frequency



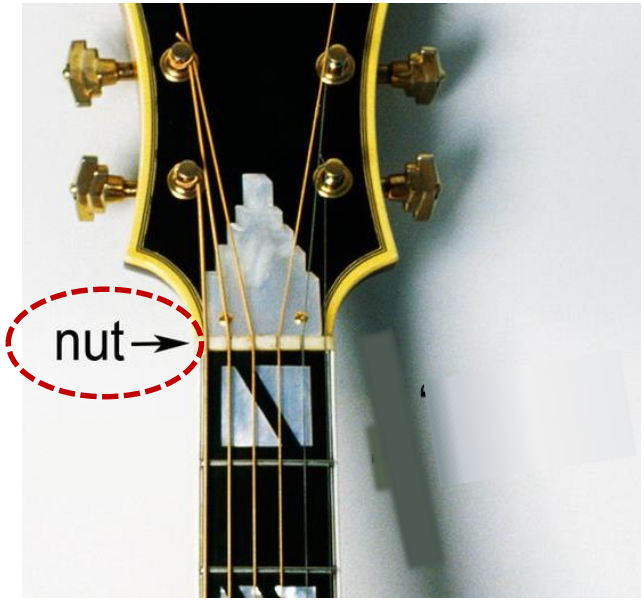
Strings

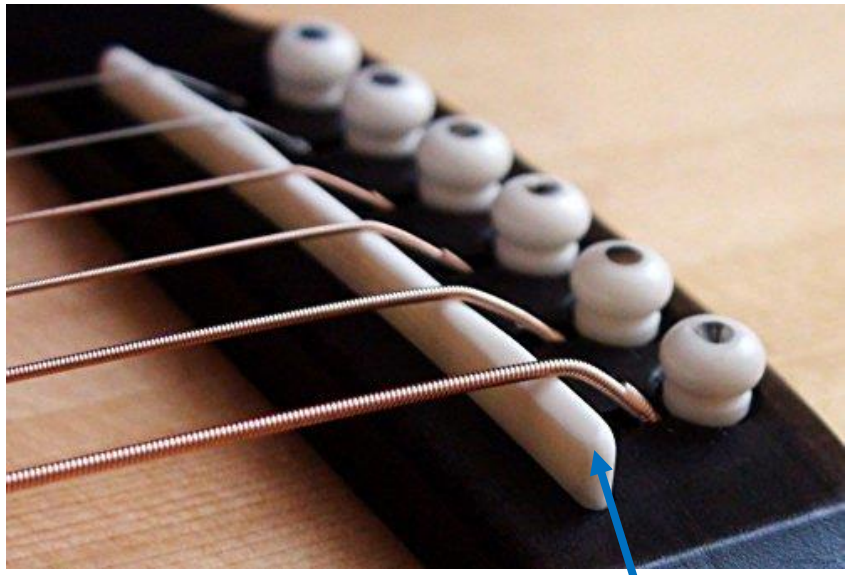
Generic String: Fixed Frequency

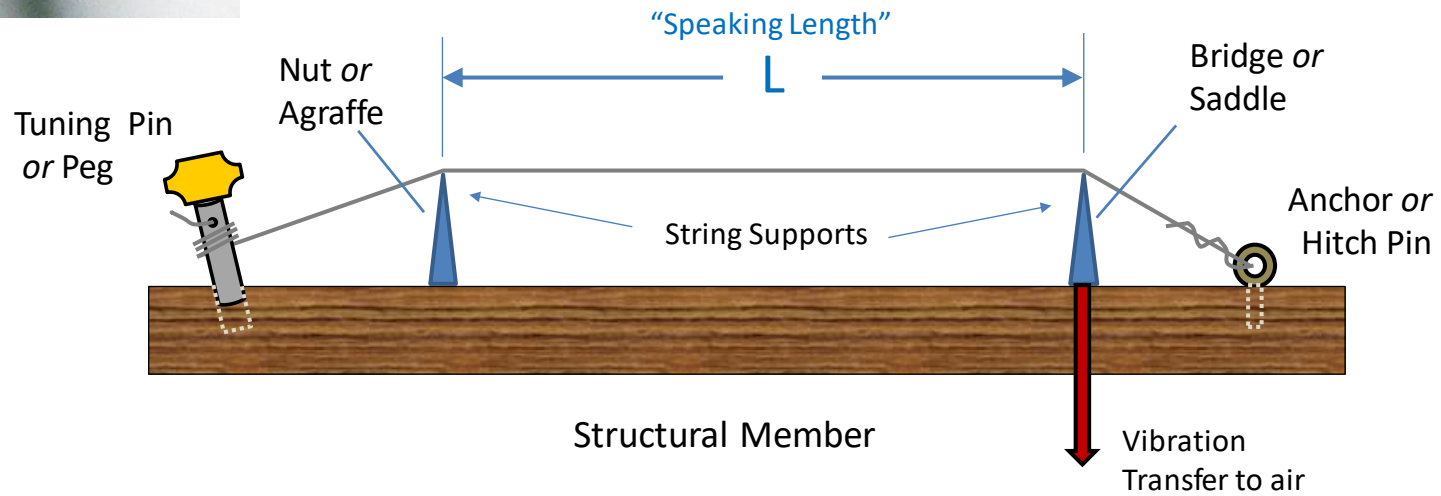


Strings

Generic String: Fixed Frequency



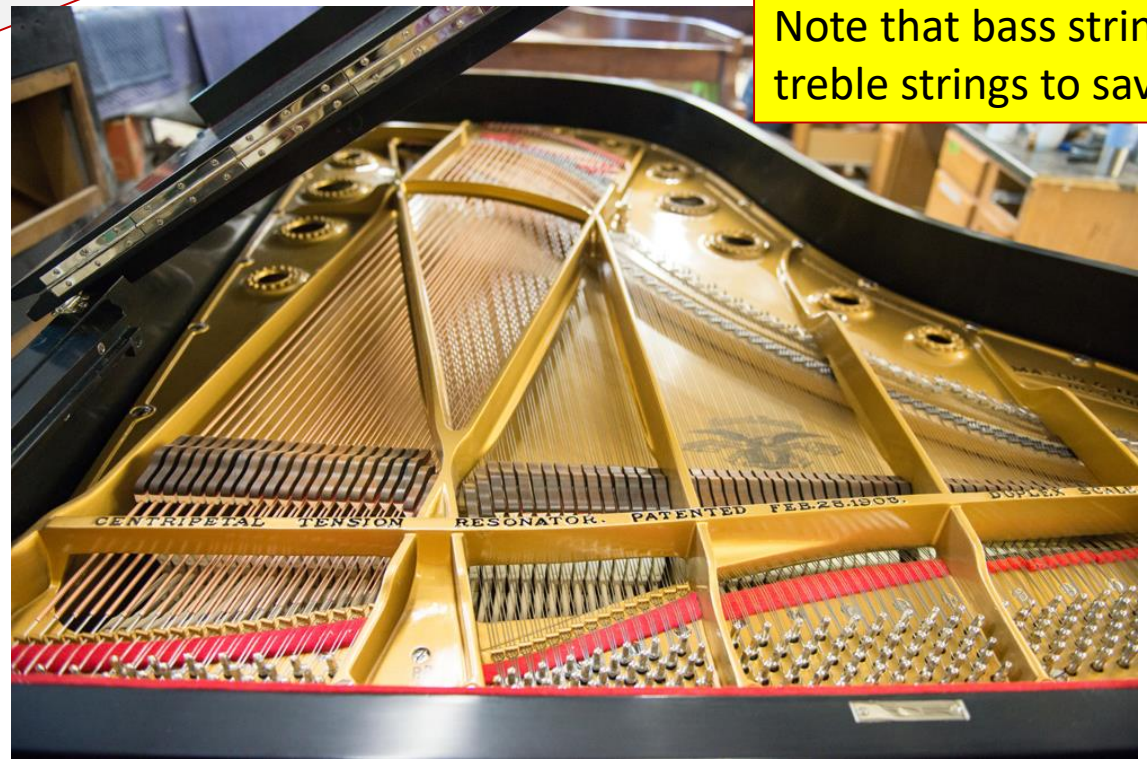




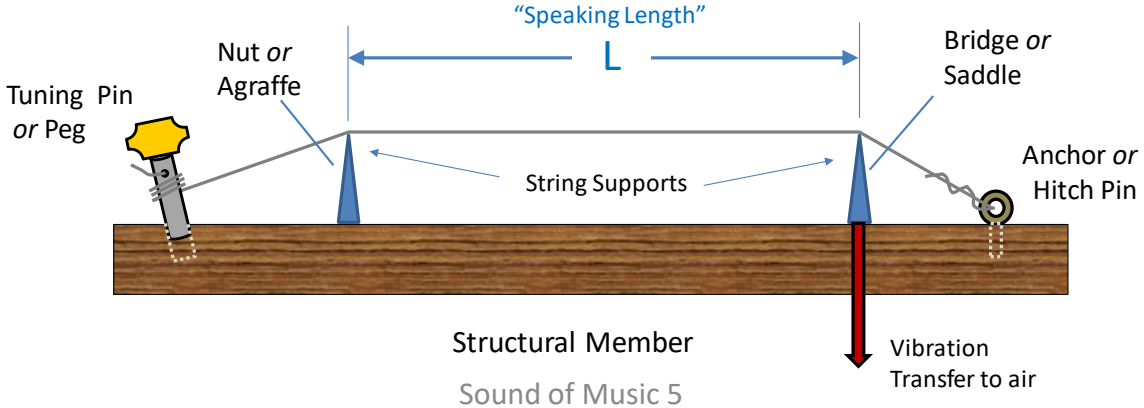
Strings

Instruments Using Fixed Frequencies

Note that bass strings pass above treble strings to save space



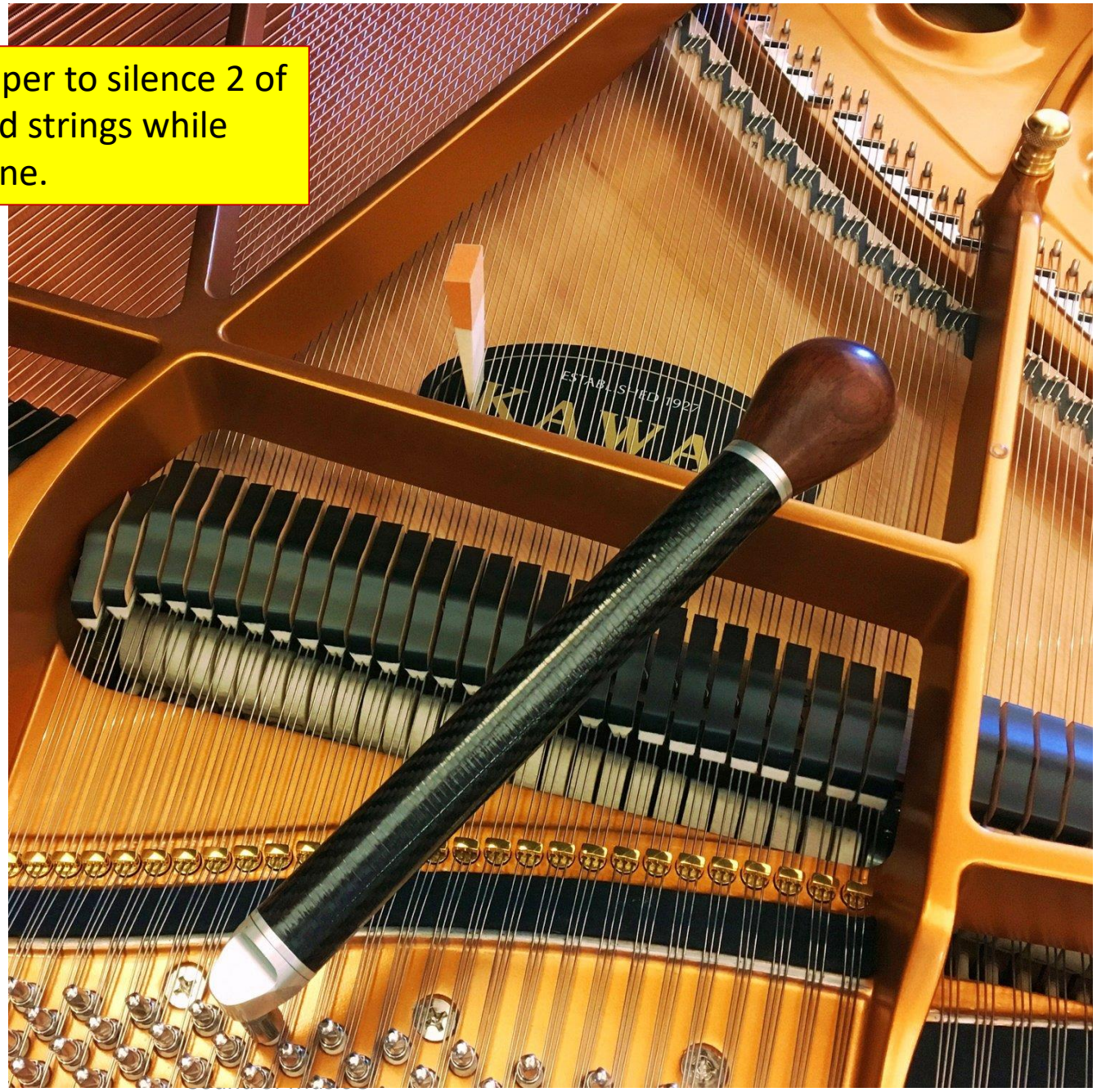
Piano



Strings

Note foam damper to silence 2 of the 3 hammered strings while tuning the 3rd one.

Tuning a Piano



Piano

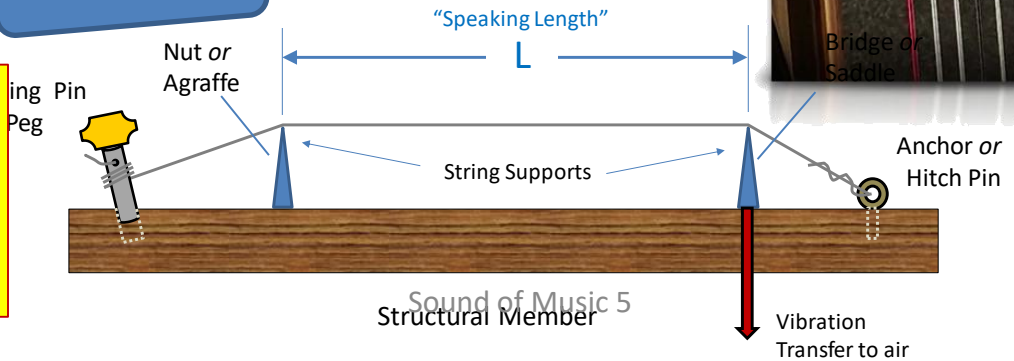
Strings

Instruments Using Fixed Frequencies

Ukrainian Bandura

Harps

Zithers



Even these types of instruments sometimes have lever mechanisms to change string lengths to achieve additional notes.

Strings

Instruments Using Variable Frequencies *(Length Change)*

Guitar

Banjo

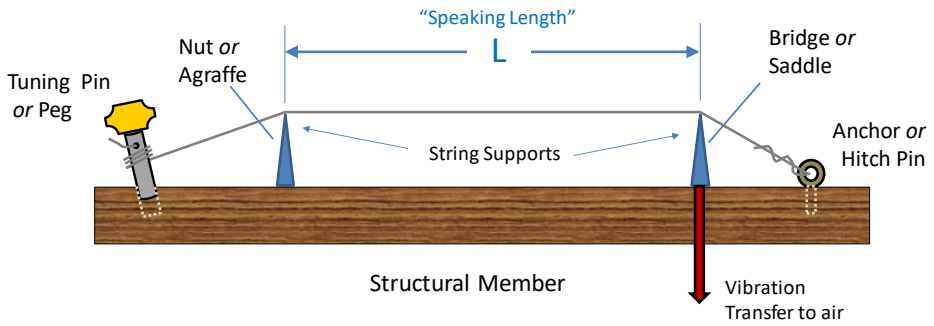
Sitar

Violin

Cello

Double Bass

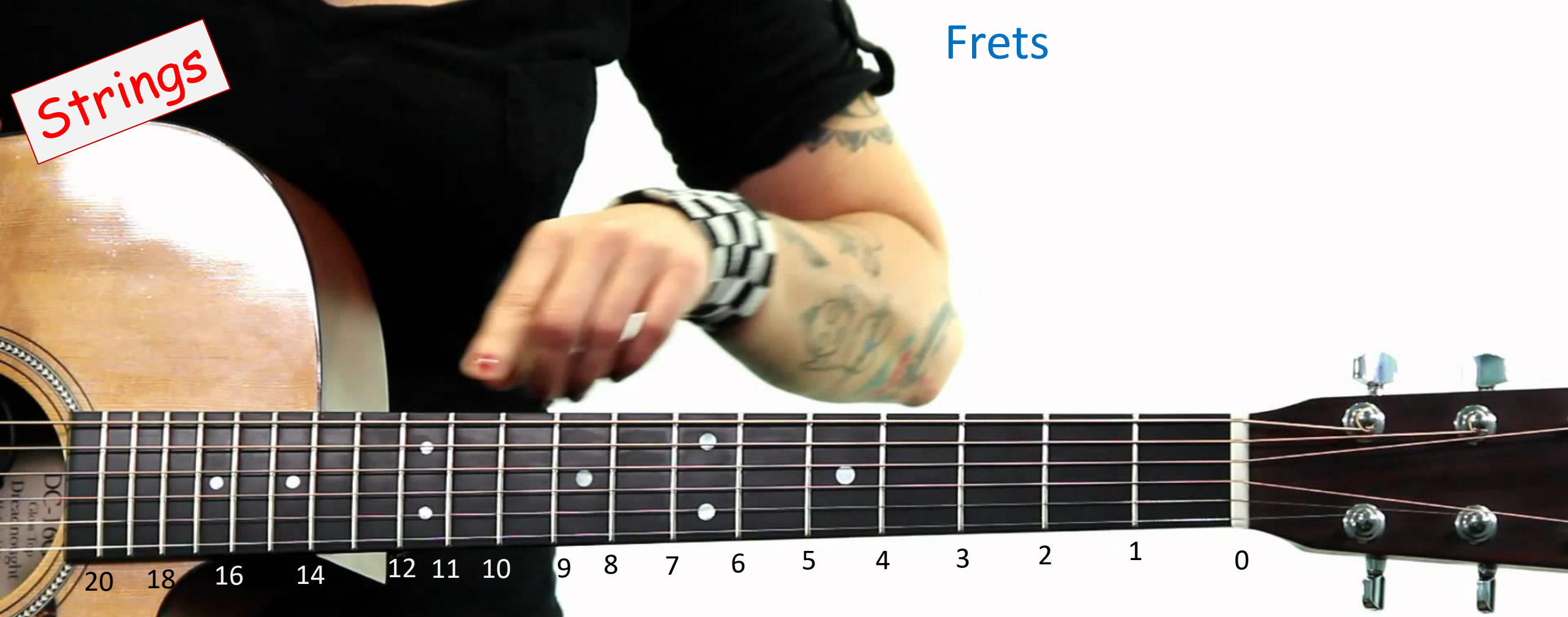
Fretted Instruments

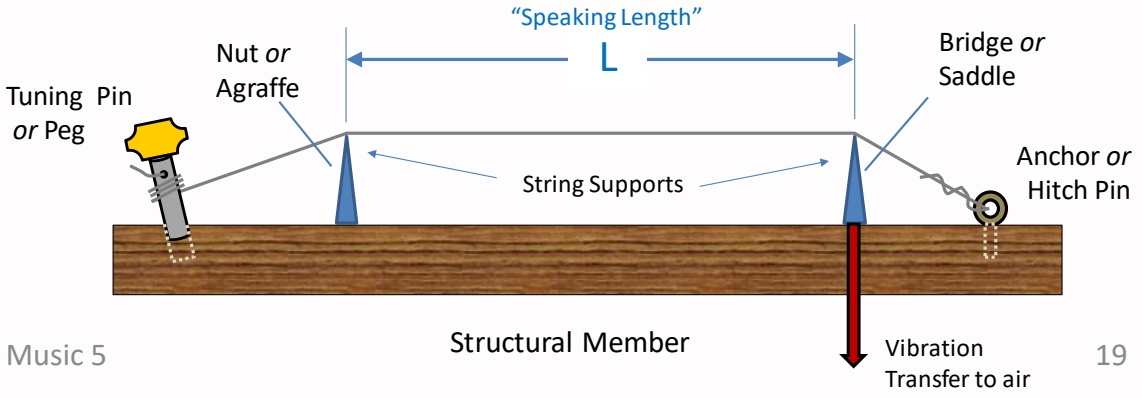


Unfretted

Frets

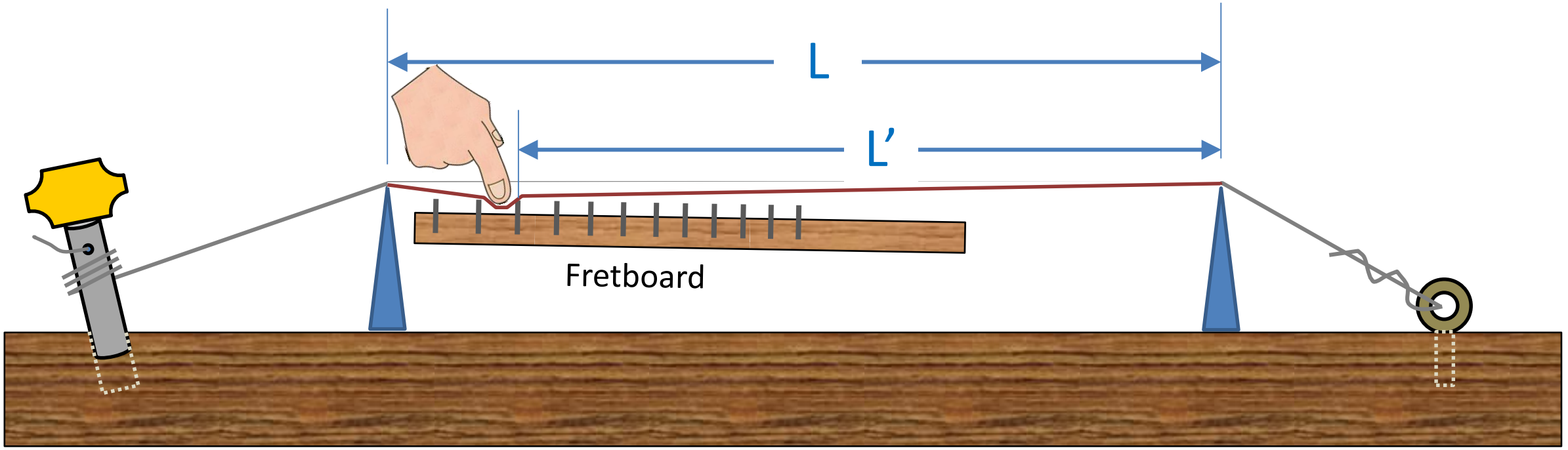
Strings





Strings

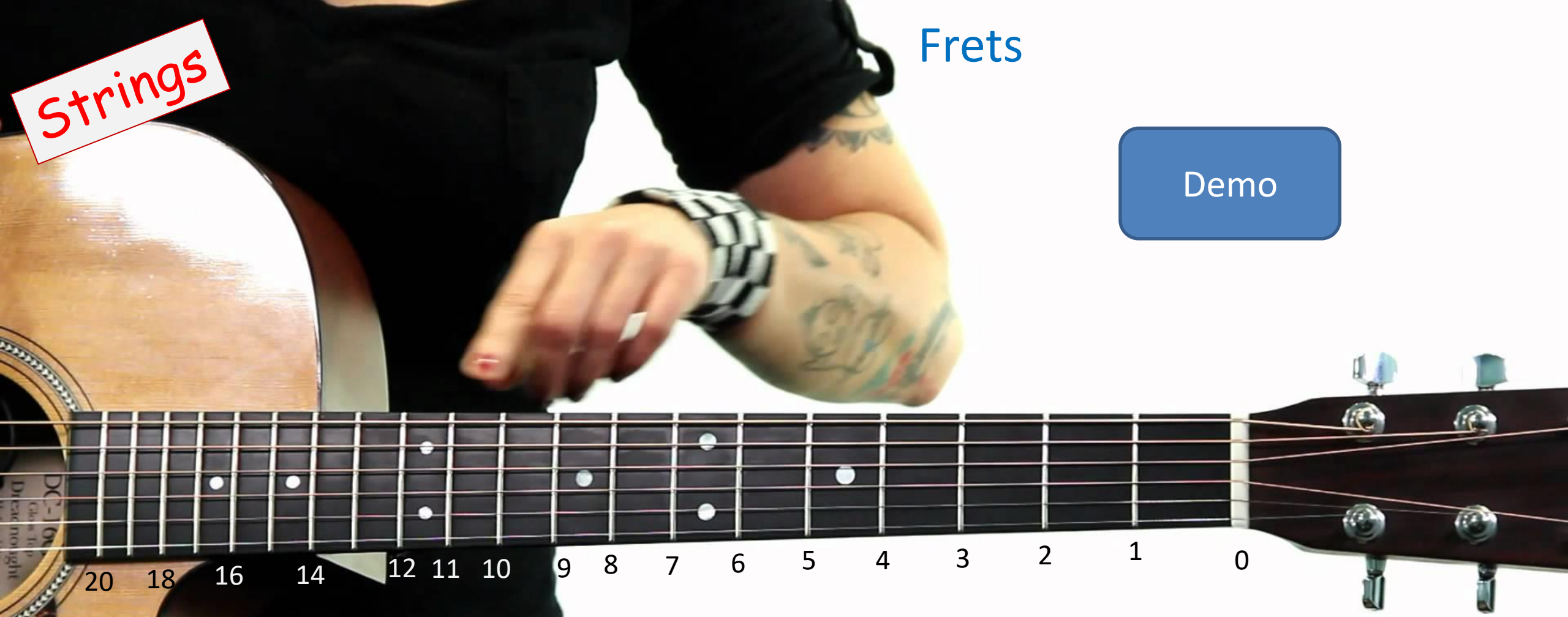
Frets

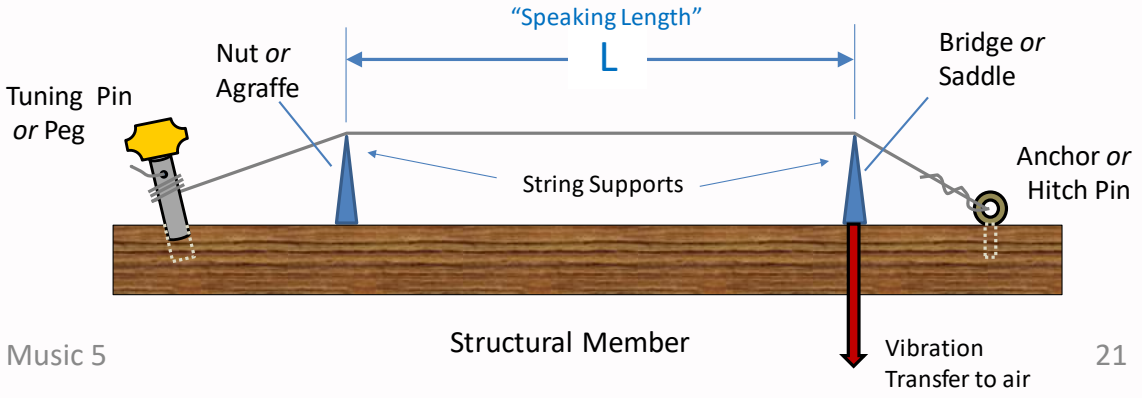


Frets

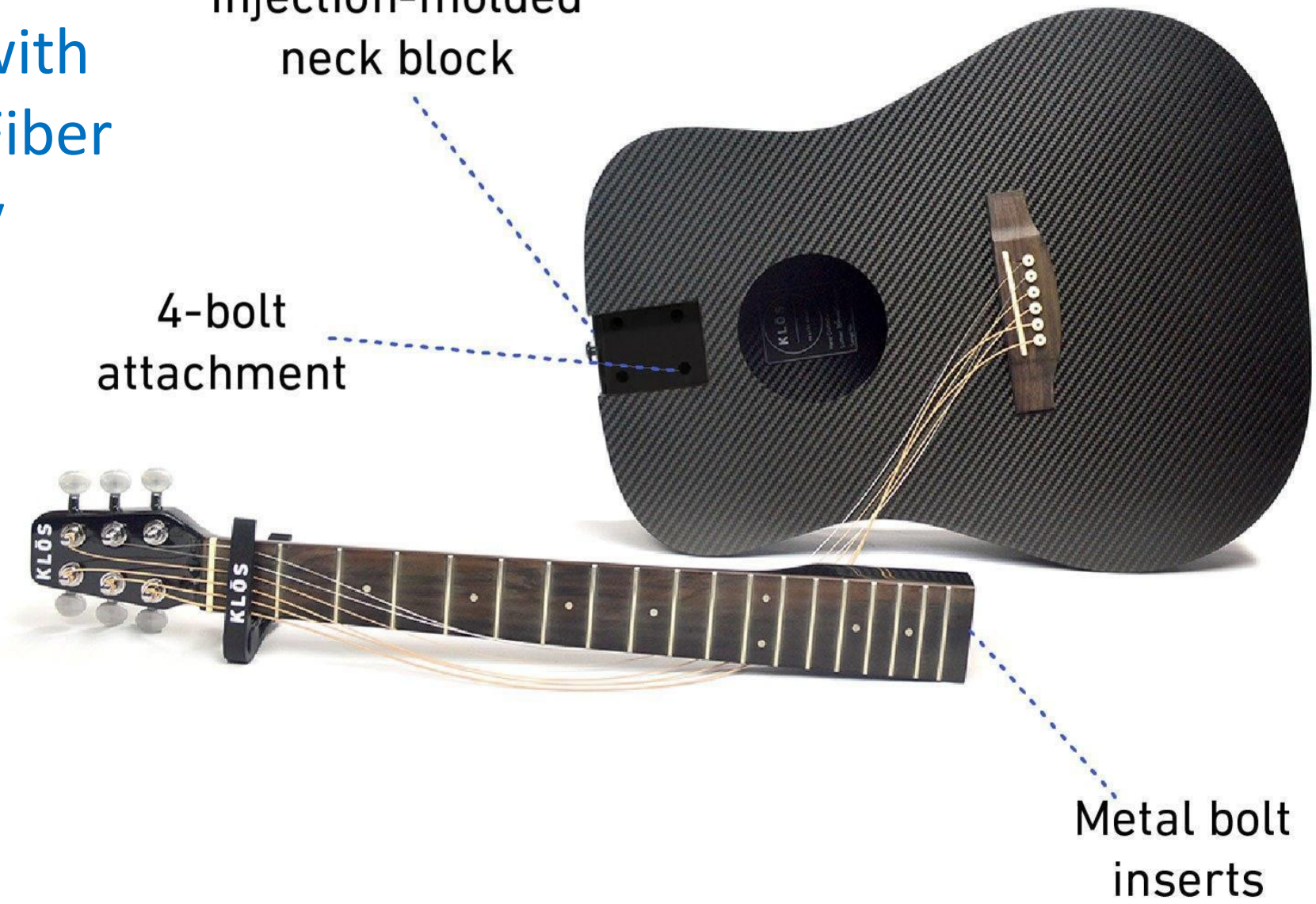
Strings

Demo



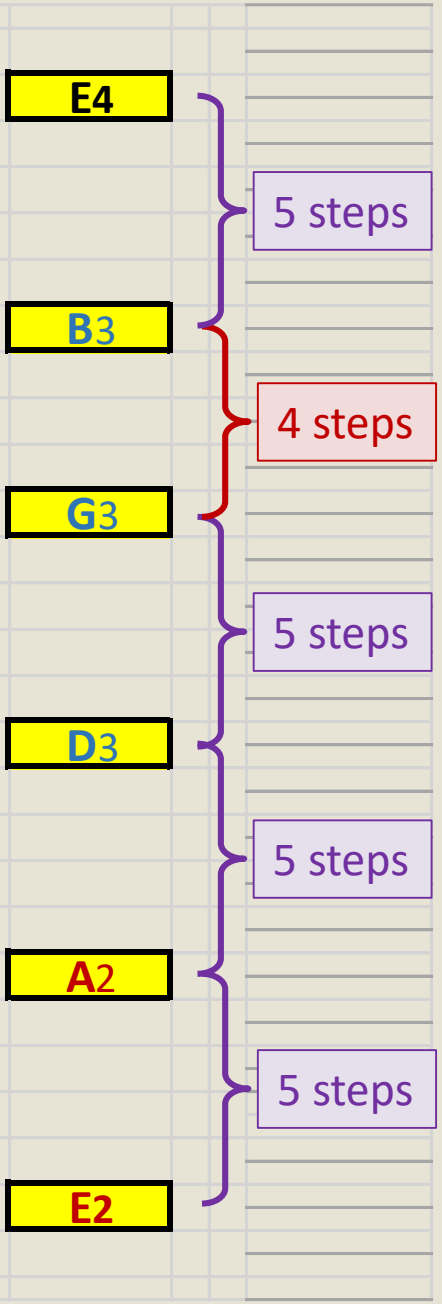


Portable Guitar with Carbon Fiber Body



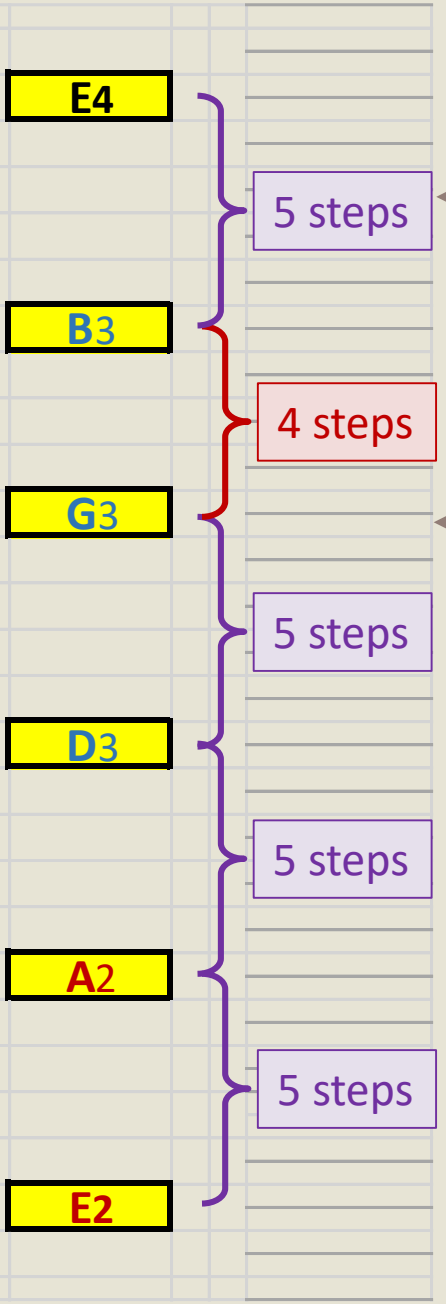
6 String Guitar Standard Tuning

Piano	MIDI	f	Chromatic Scale	Note
45	**65**	**349.2**		F 4
44	**64**	**329.6**		E 4
43	**63**	**311.1**		D#/E♭ 4
42	**62**	**293.7**		D 4
41	**61**	**277.2**		C#/D♭ 4
40	**60**	**261.6**		**C 4**
39	59	246.9		B 3
38	58	233.1		A#/B♭ 3
37	57	220		A 3
36	56	207.7		G#/A♭ 3
35	55	196.0		G 3
34	54	185.0		F#/G♭ 3
33	53	174.6		F 3
32	52	164.8		E 3
31	51	155.6		D#/E♭ 3
30	50	146.8		D 3
29	49	138.6		C#/D♭ 3
28	48	130.8		C 3
27	47	123.5		B 2
26	46	116.5		A#/B♭ 2
25	45	110		A 2
24	44	103.8		G#/A♭ 2
23	43	98.0		G 2
22	42	92.5		F#/G♭ 2
21	41	87.3		F 2
20	40	82.4		E 2
19	39	77.8		D#/E♭ 2



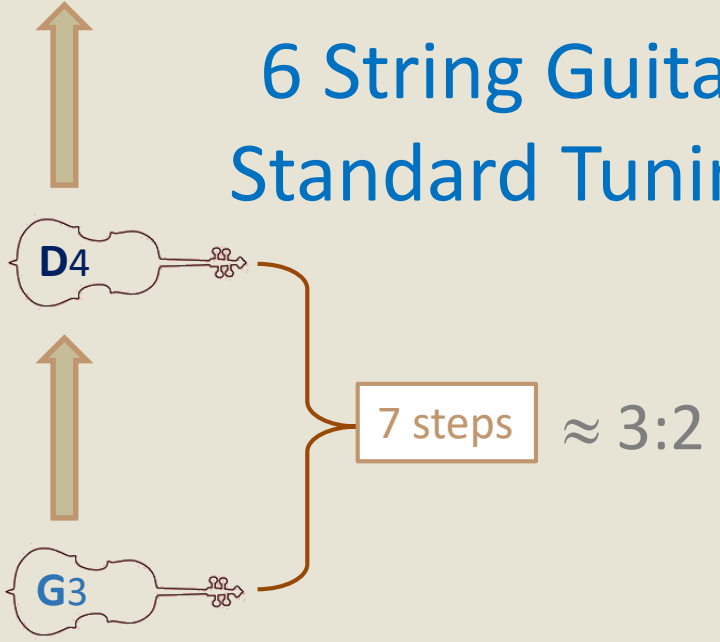
6 String Guitar Standard Tuning

Piano	MIDI	f	Chromatic Scale	Note
45	**65**	**349.2**		F 4
44	**64**	**329.6**		E 4
43	**63**	**311.1**		D#/E♭ 4
42	**62**	**293.7**		D 4
41	**61**	**277.2**		C#/D♭ 4
40	**60**	**261.6**		**C 4**
39	59	246.9		B 3
38	58	233.1		A#/B♭ 3
37	57	220		A 3
36	56	207.7		G#/A♭ 3
35	55	196.0		G 3
34	54	185.0		F#/G♭ 3
33	53	174.6		F 3
32	52	164.8		E 3
31	51	155.6		D#/E♭ 3
30	50	146.8		D 3
29	49	138.6		C#/D♭ 3
28	48	130.8		C 3
27	47	123.5		B 2
26	46	116.5		A#/B♭ 2
25	45	110		A 2
24	44	103.8		G#/A♭ 2
23	43	98.0		G 2
22	42	92.5		F#/G♭ 2
21	41	87.3		F 2
20	40	82.4		E 2
19	39	77.8		D#/E♭ 2



≈ 5:4

≈ 4:3



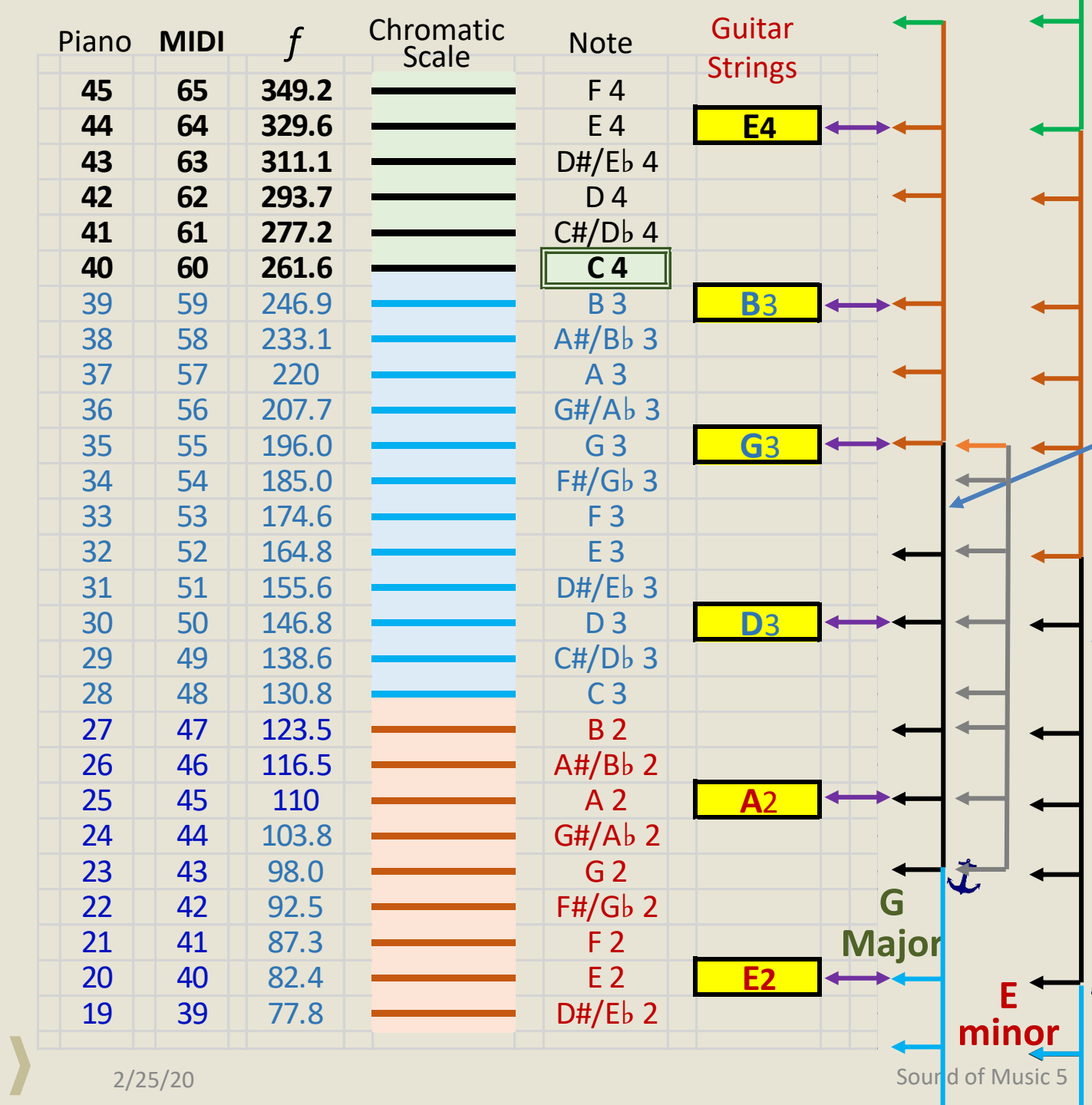
7 steps

≈ 3:2

Violin
(4 strings each 7 steps apart)

6 String Guitar Standard Tuning

Piano	MIDI	f	Chromatic Scale	Note	Guitar Strings
45	**65**	**349.2**		F 4	
44	**64**	**329.6**		E 4	**E4**
43	**63**	**311.1**		D#/E♭ 4	
42	**62**	**293.7**		D 4	
41	**61**	**277.2**		C#/D♭ 4	
40	**60**	**261.6**		**C 4**	
39	59	246.9		B 3	**B3**
38	58	233.1		A#/B♭ 3	
37	57	220		A 3	
36	56	207.7		G#/A♭ 3	
35	55	196.0		G 3	**G3**
34	54	185.0		F#/G♭ 3	
33	53	174.6		F 3	
32	52	164.8		E 3	
31	51	155.6		D#/E♭ 3	
30	50	146.8		D 3	**D3**
29	49	138.6		C#/D♭ 3	
28	48	130.8		C 3	
27	47	123.5		B 2	
26	46	116.5		A#/B♭ 2	
25	45	110		A 2	**A2**
24	44	103.8		G#/A♭ 2	
23	43	98.0		G 2	
22	42	92.5		F#/G♭ 2	
21	41	87.3		F 2	
20	40	82.4		E 2	**E2**
19	39	77.8		D#/E♭ 2	



All 6 belong to *two* of the Pentatonic Scales

They also belong to 6 Diatonic Scales:

C Major	A minor
D Major	B minor
G Major	E minor

G Major Root Chord
(cannot be played on open strings)

Strings

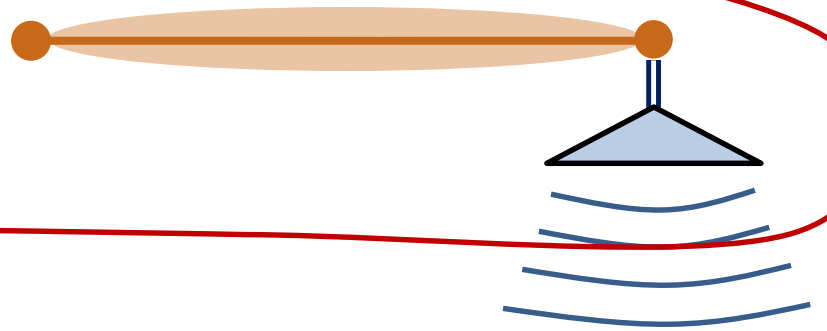
String Instruments

Three main problems:

1. Excitation EASY
   - How to get the string vibrating

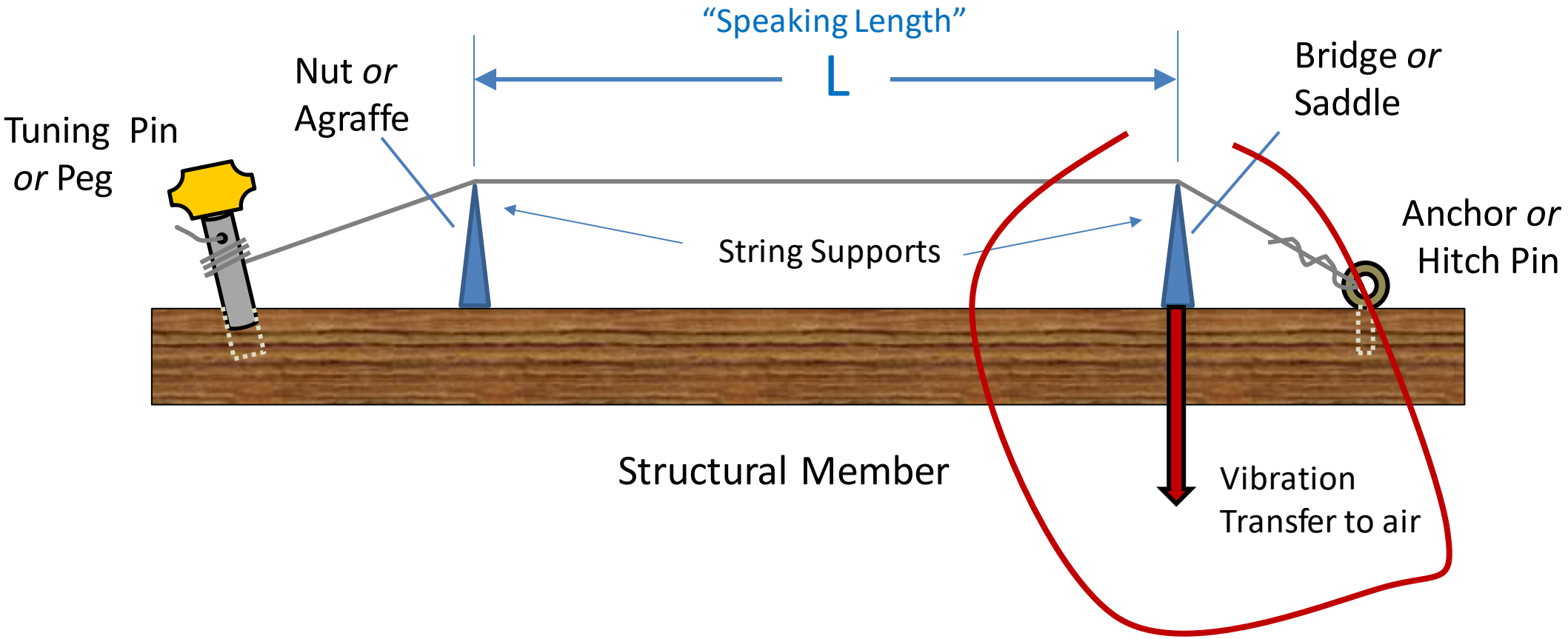
2. Frequency Control EASY
   - Playing desired notes

3. Getting Sound Out HARD
   - Coupling string vibrations to sound waves



Strings

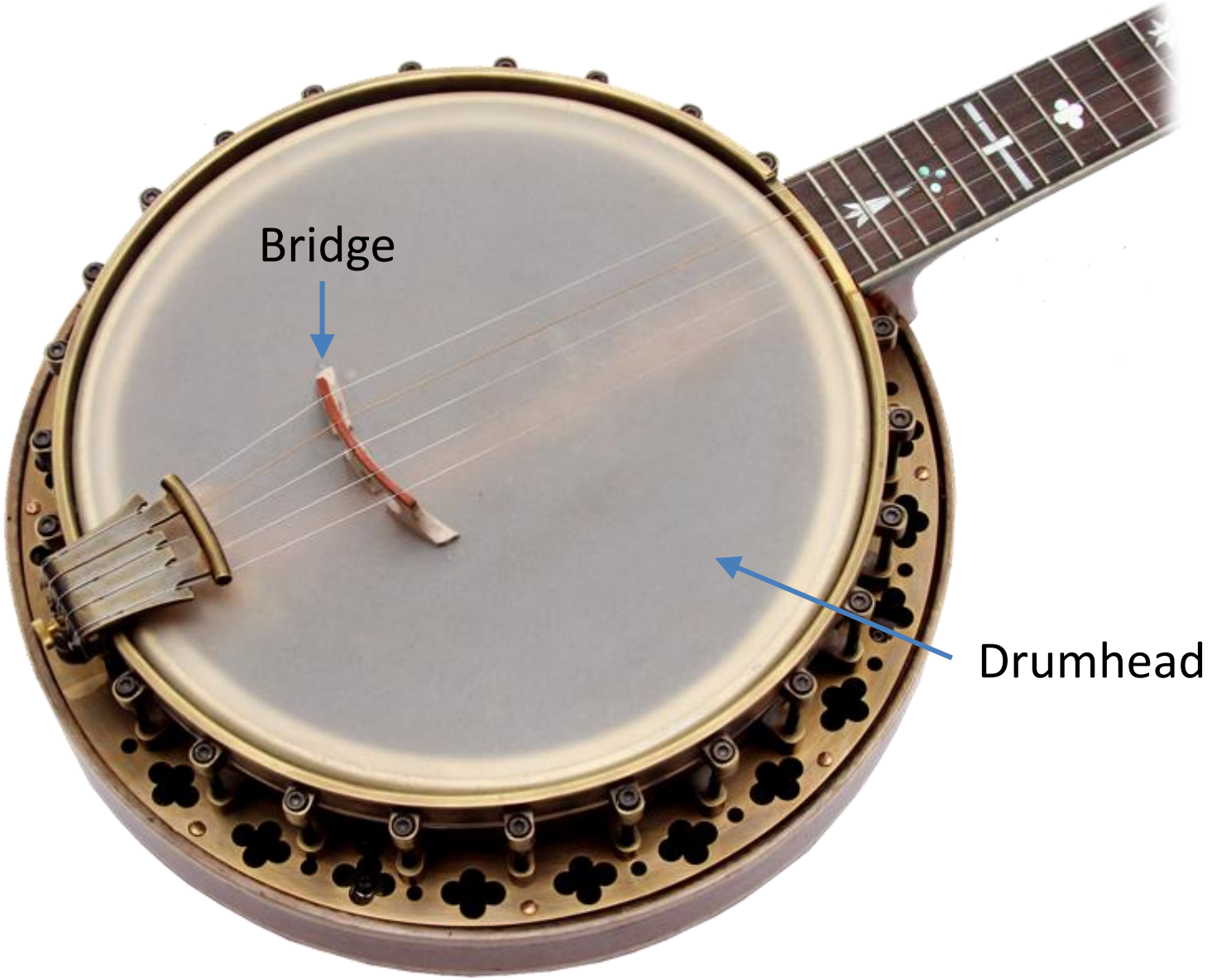
Generic String:
Transferring String Vibrations into the Air



Strings

Banjo: Transferring String Vibrations into the Air

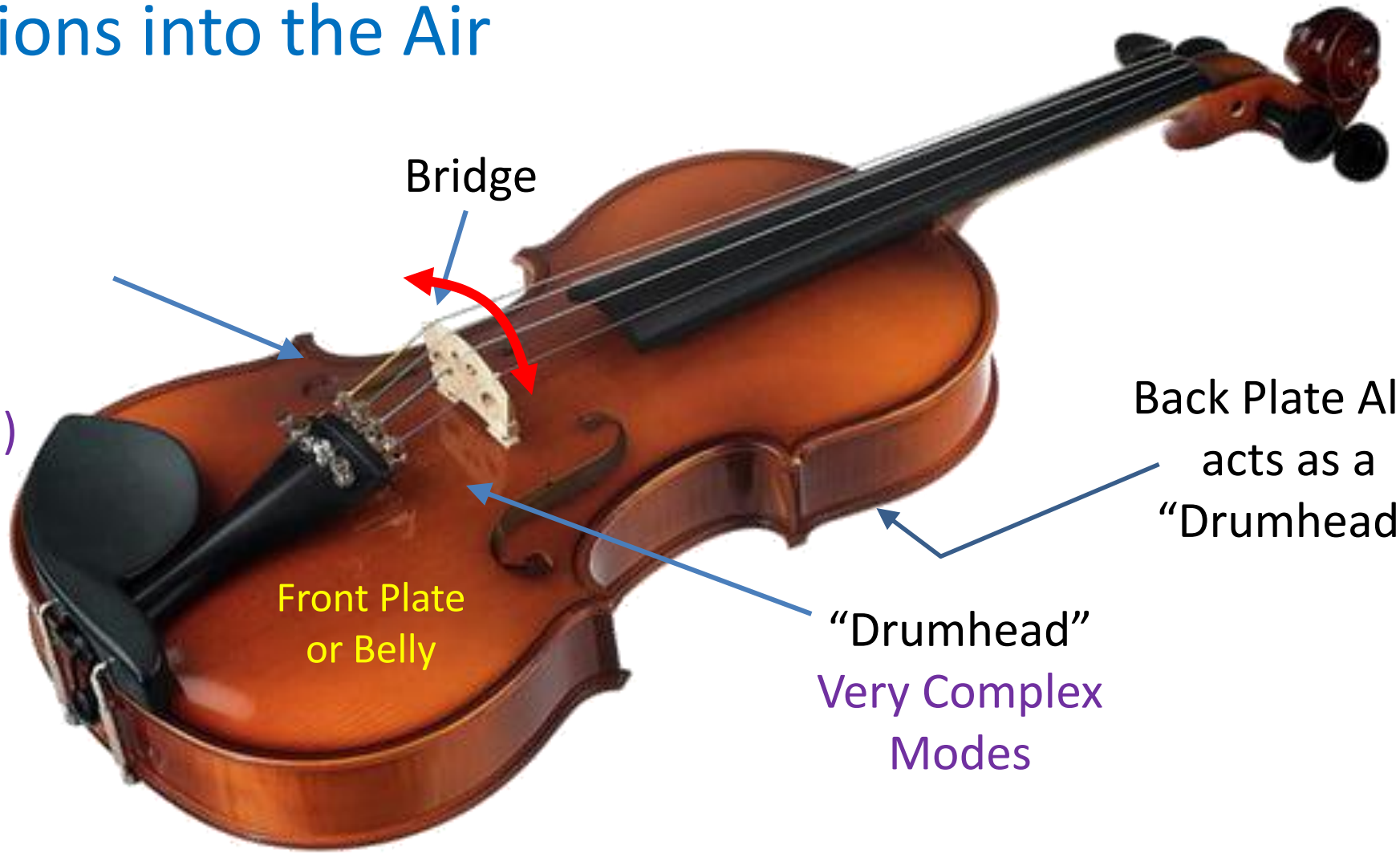
Closed Back Banjo



Strings

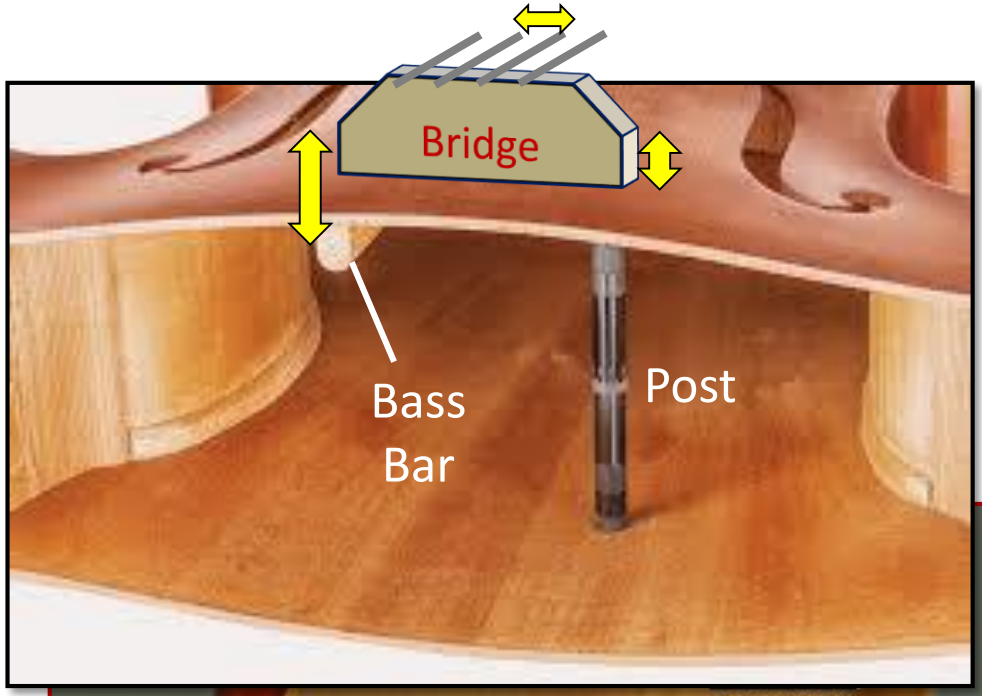
Violin: Transferring String Vibrations into the Air

f Holes make body a **Helmholtz Resonator** (Bass Response)



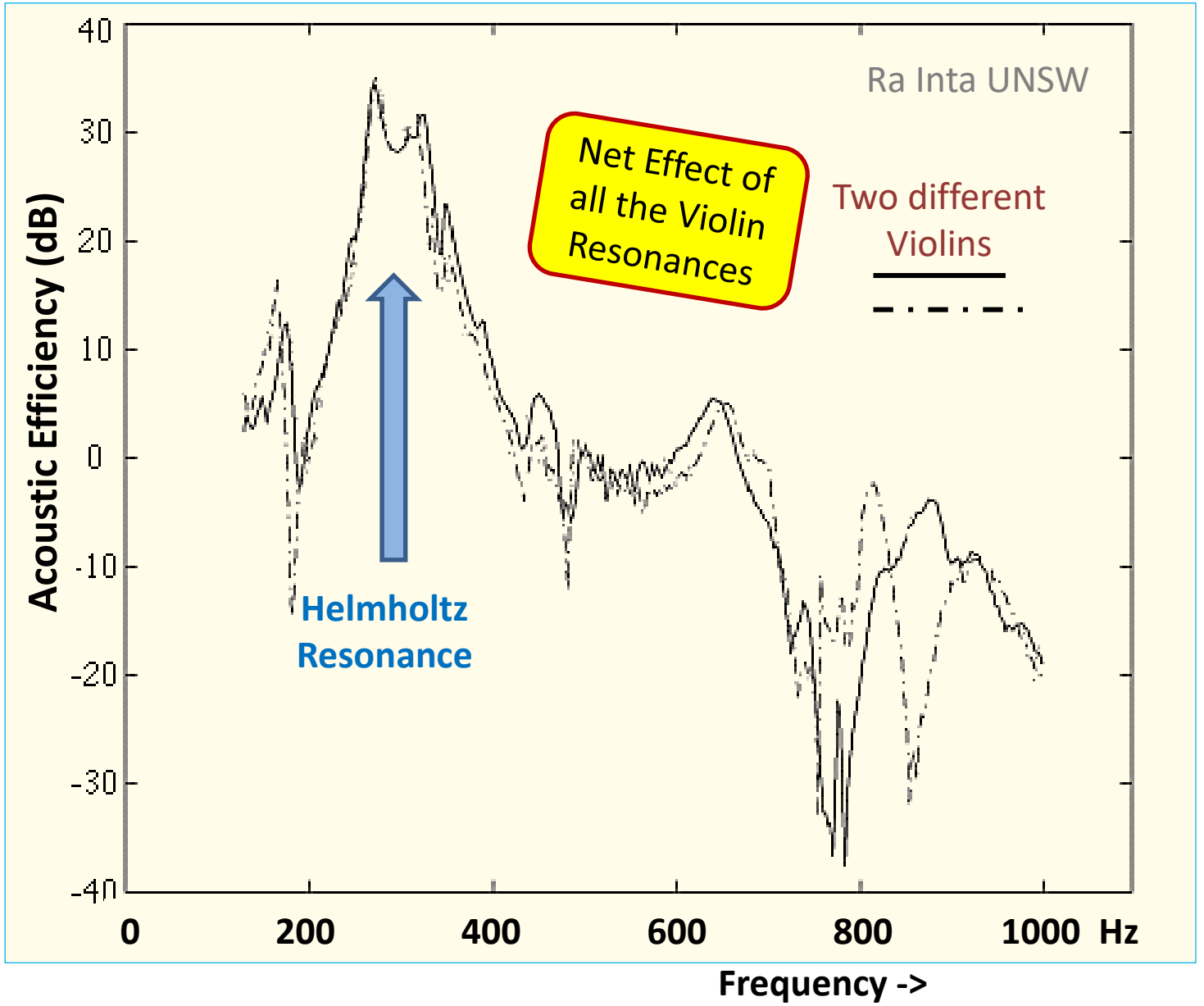
Strings

Violin: Transferring String Vibrations into the Air



Strings

Violin:
How Efficiently String Vibrations are Converted to Sound in the Air

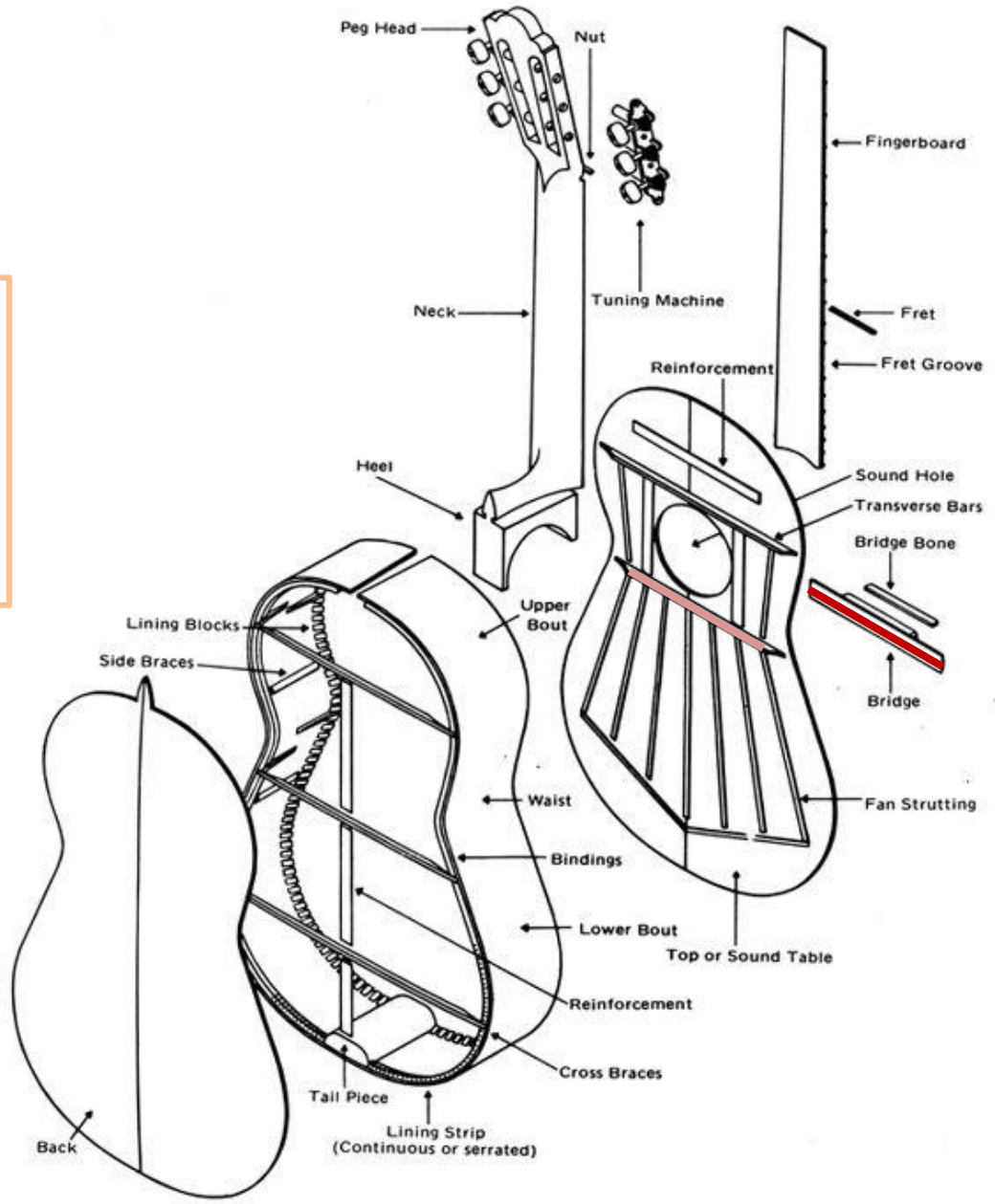


Strings

Guitar Internal Structure

String vibrations excite:

- Drumhead-like modes in top & bottom
- Helmholtz Resonator (body + hole)



Strings

Piano Sounding Board

- Sitka spruce
- Thickness varies ¼ to 3/8 “
- Crowned upward for strength
- Has carefully controlled membrane resonances