OSHER LIFELONG LEARNING INSTITUTE

Sound of Music

How It Works

Session 2
Resonance: Building Musical Sounds

Ocarina (Helmholtz Resonator)
Lena Leclaire 2012

Legend of Zelda Medley

OLLI at Illinois

Spring 2020

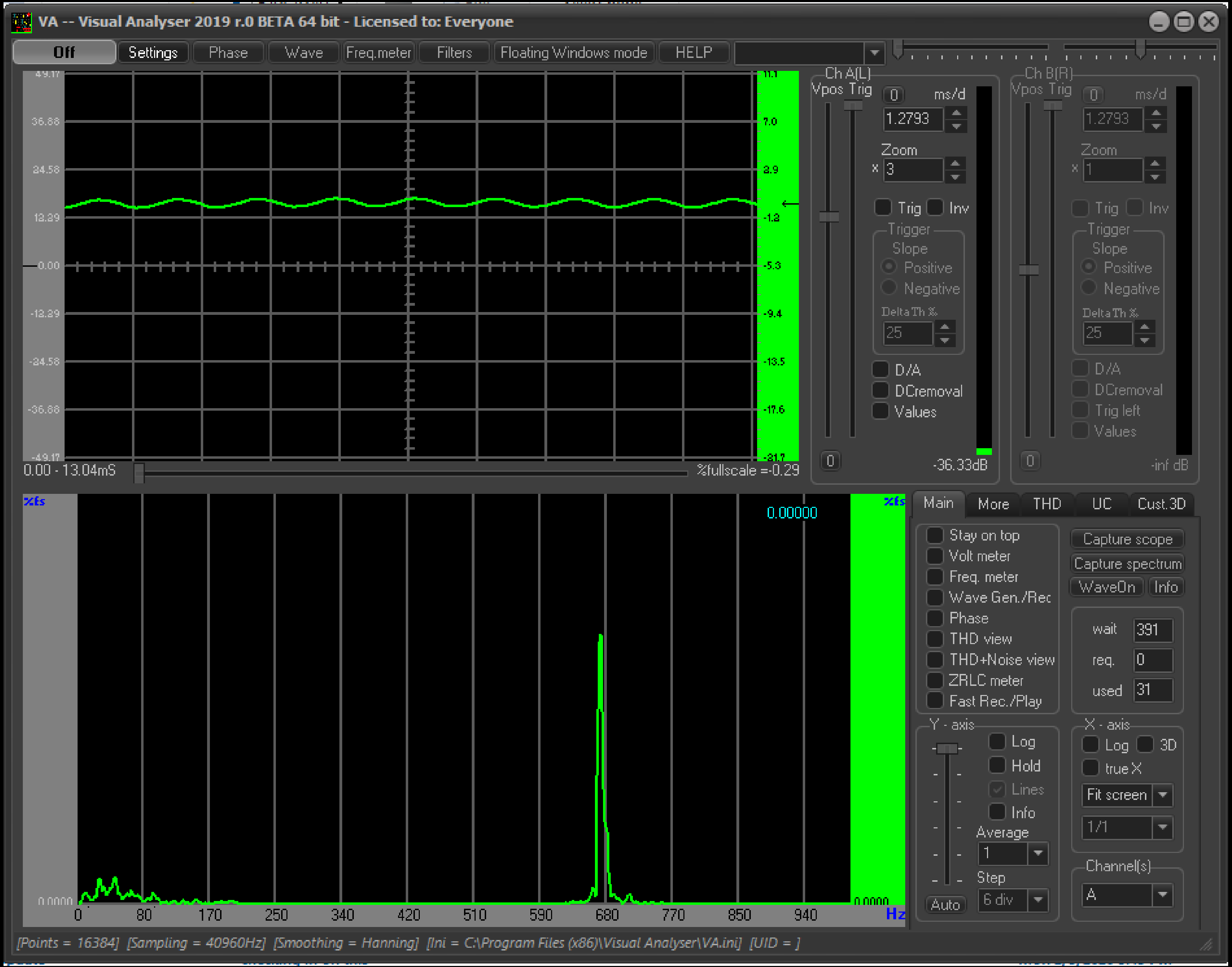
D. H. Tracy

Course Outline

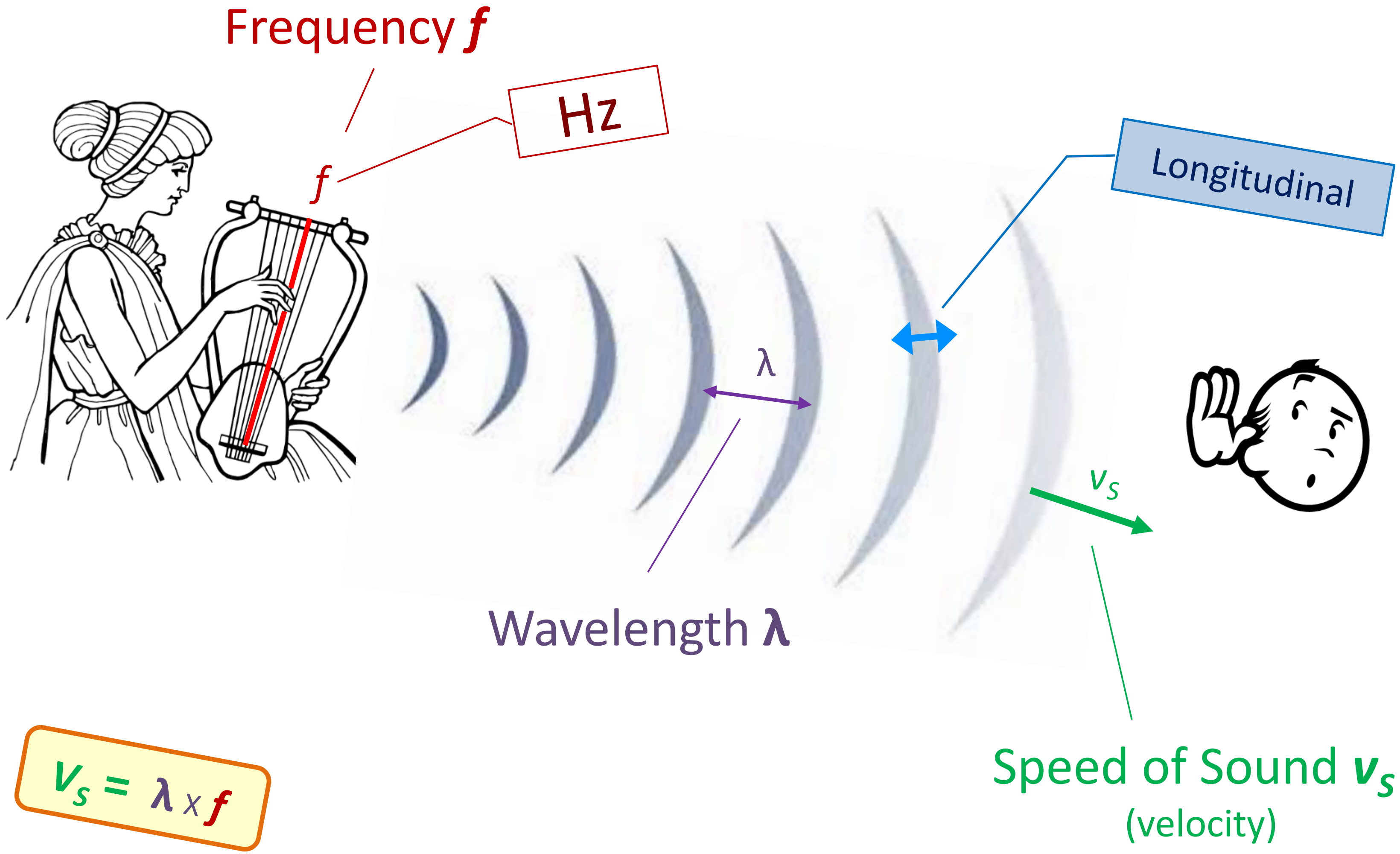
1. Building Blocks: Some basic concepts
2. Resonance: Building Musical Sounds
3. Hearing and the Ear
4. Musical Scales
5. Musical Instruments
6. Singing and Musical Notation
7. Harmony and Dissonance; Chords
8. Combining the Elements of Music

Visual Analyzer Demo

Whistle

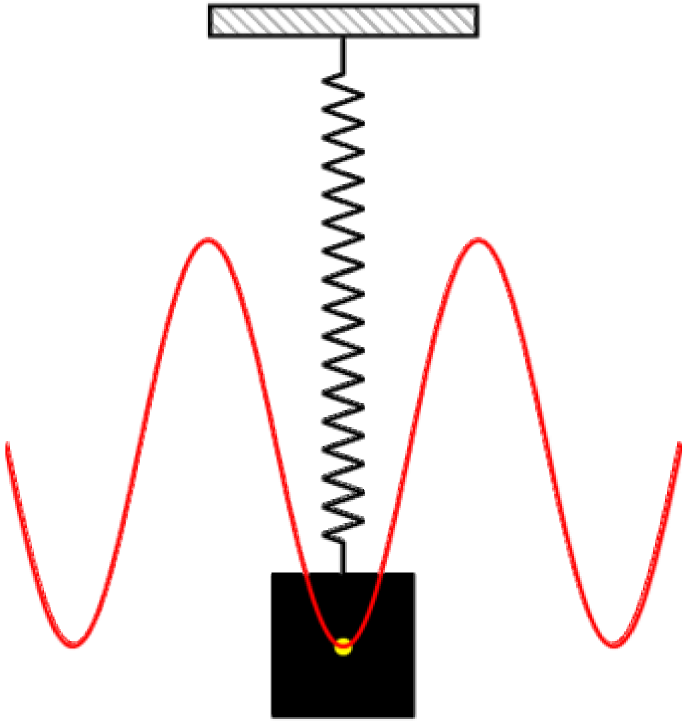


Sound As Compression Waves

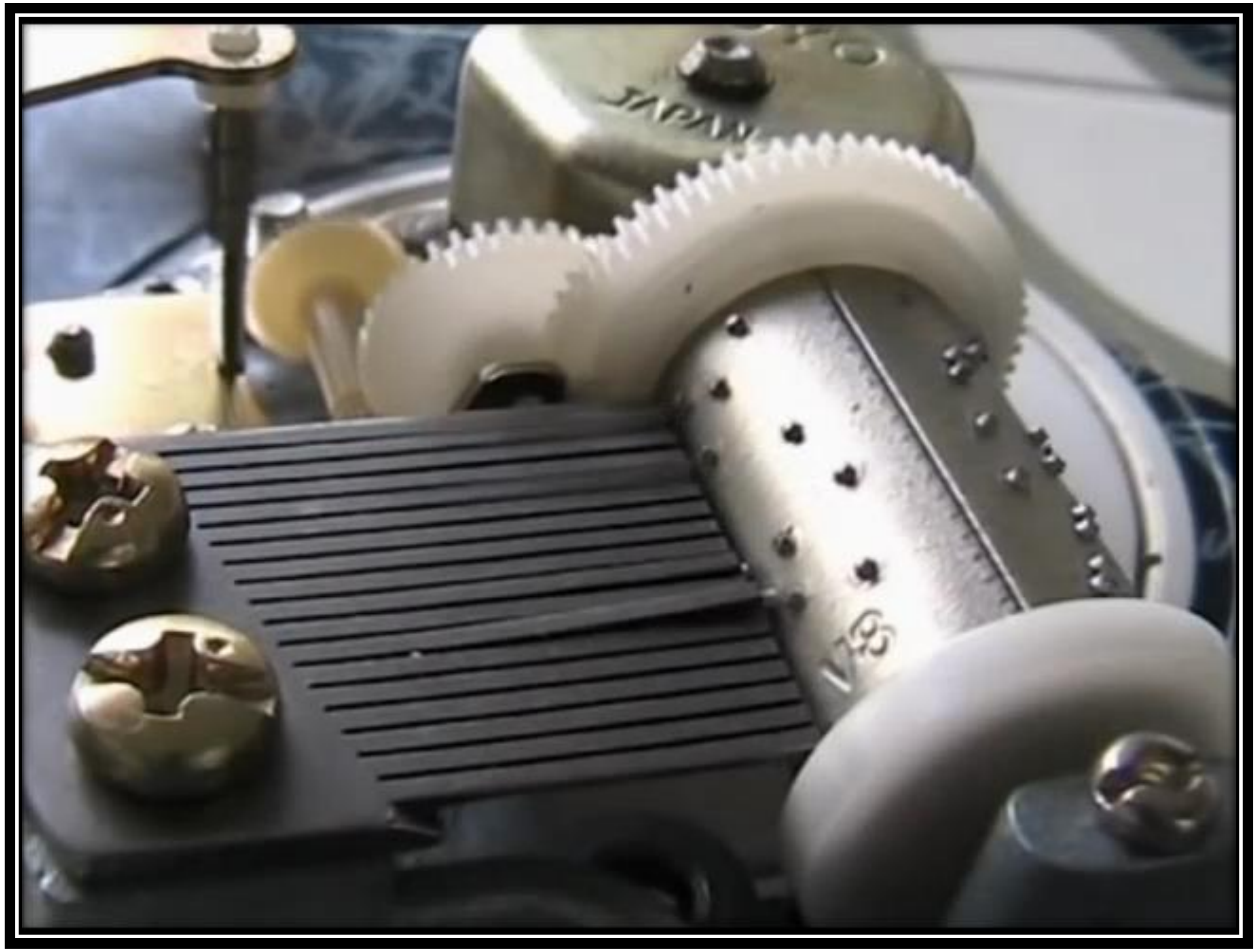


$V_S = \lambda \times f$

Simple Harmonic Oscillator



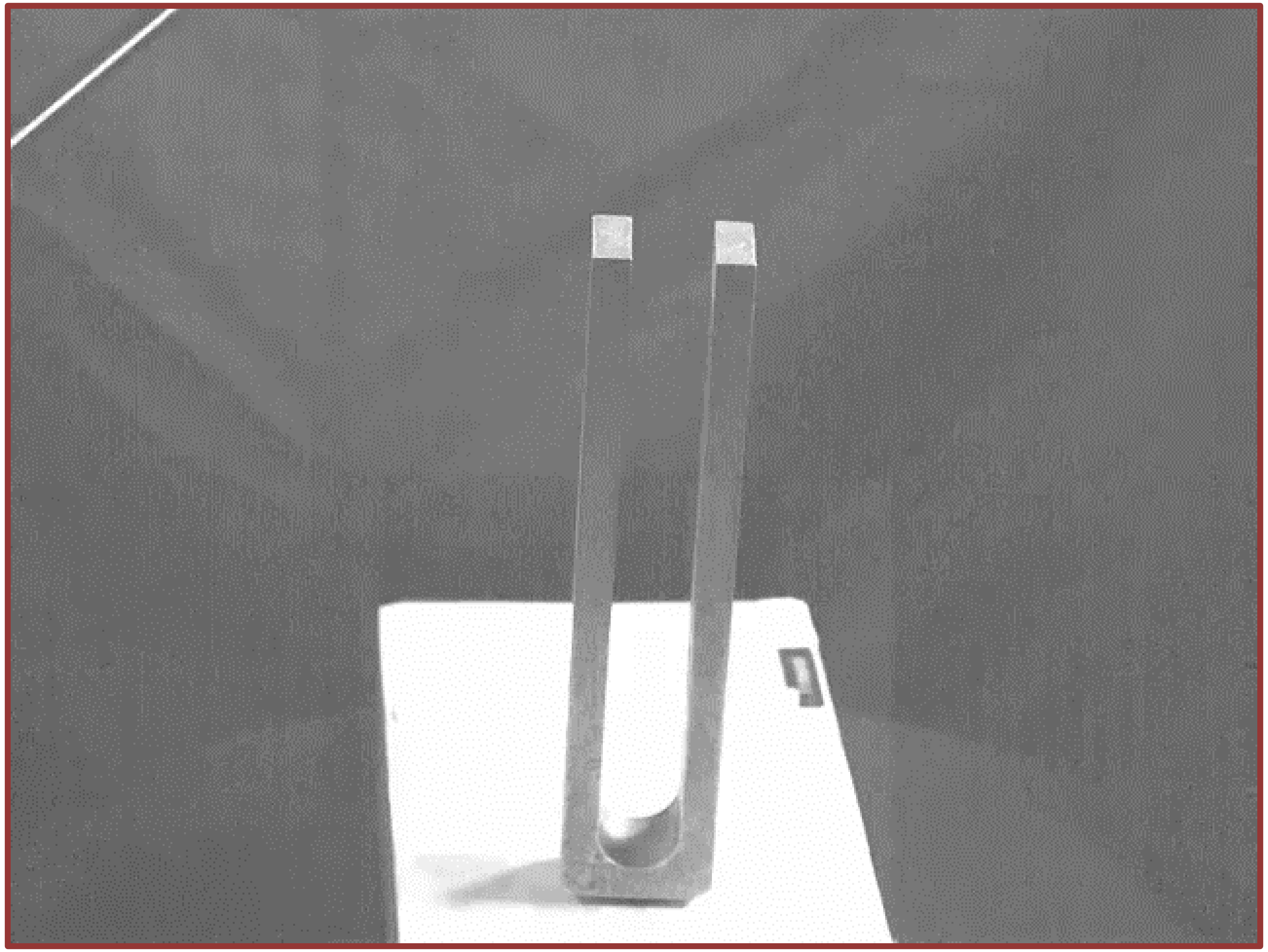
Imgur.com



James Dodd: You-Tube

Tuning Fork

Slo-Motion
Video



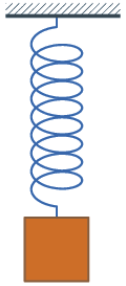
Michigan Tech
YouTube
9/11/2014

Resonators can be excited by well-timed nudges

How can we make Sine Waves?

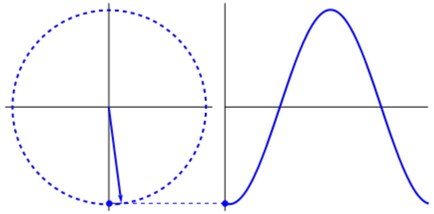
- Simple Harmonic Oscillators do it

Simple Pendulum

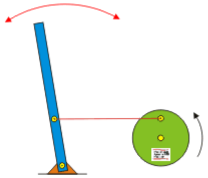


Mass on Spring

e.g. Tuning Fork



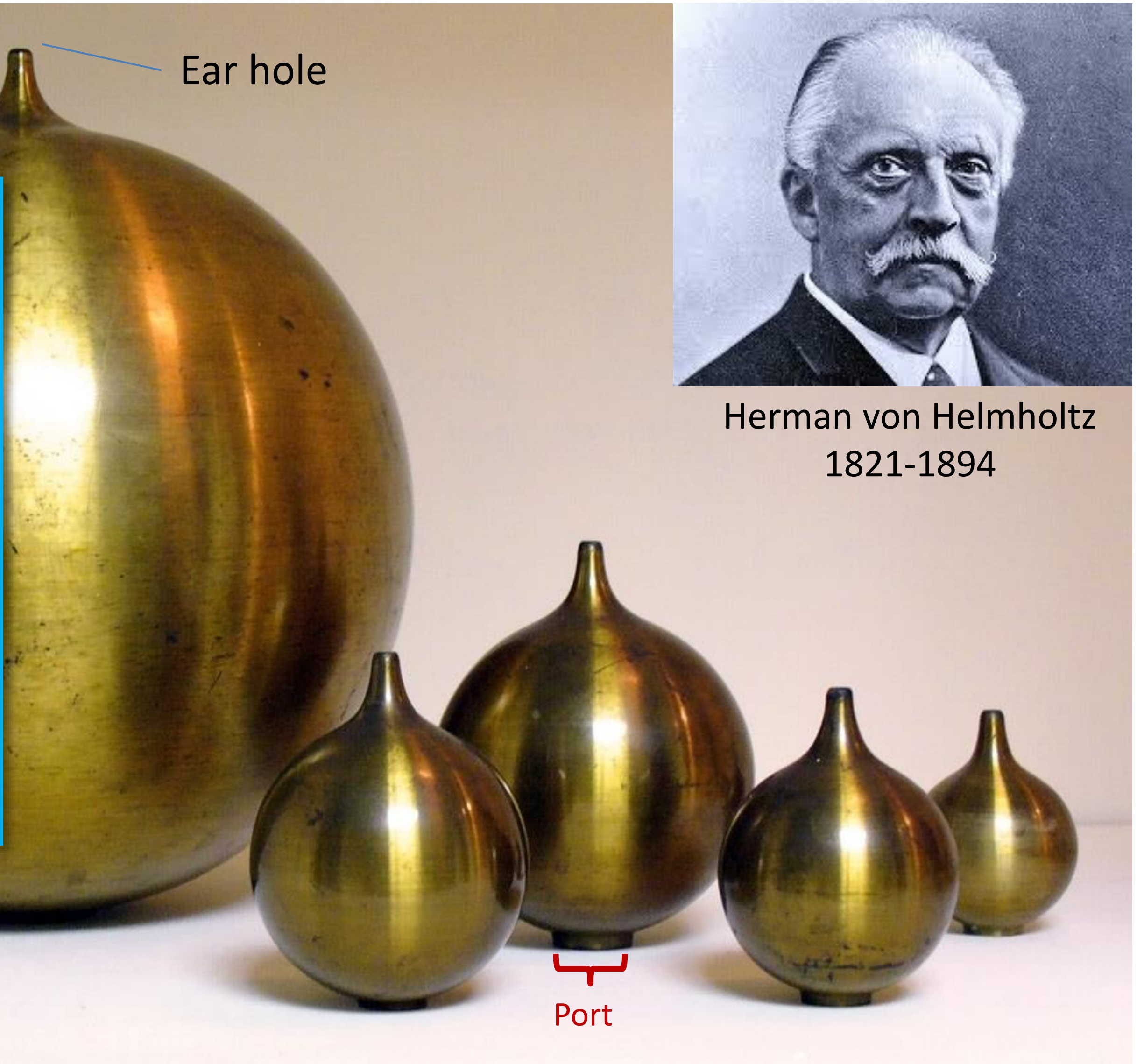
Circular Projection

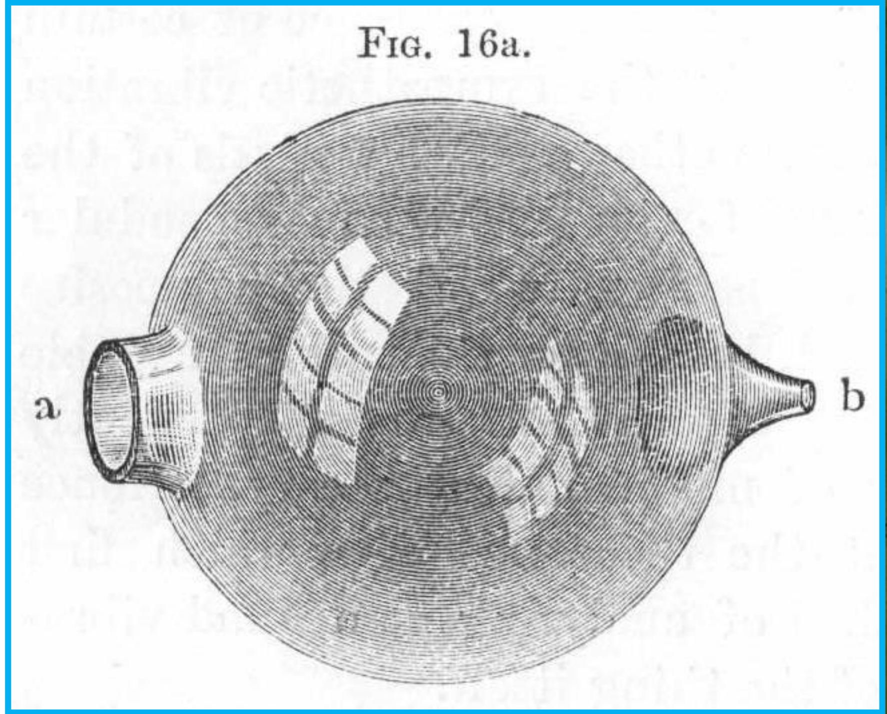


e.g. Rotational Crank Mechanism

- Electronics can also do it

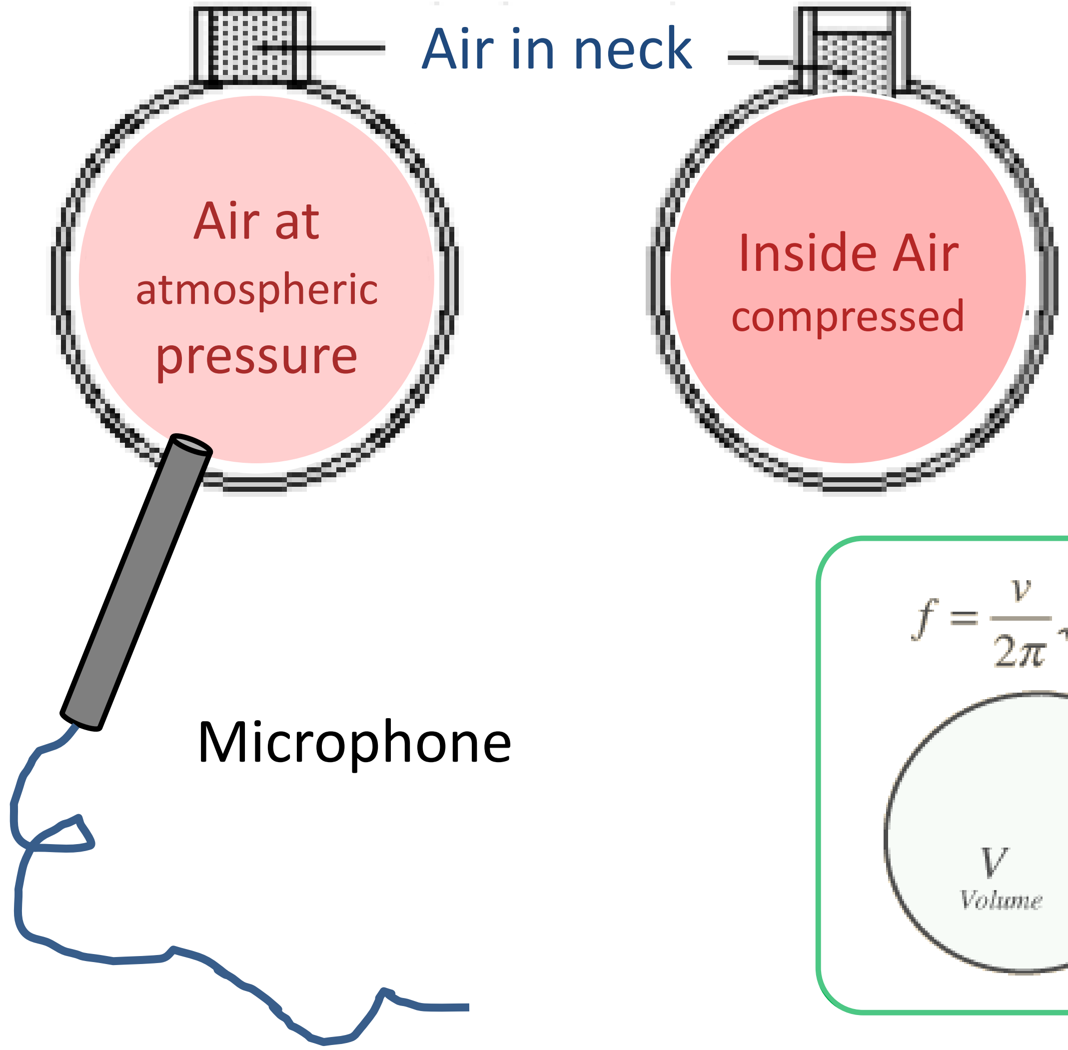
Helmholtz Resonators



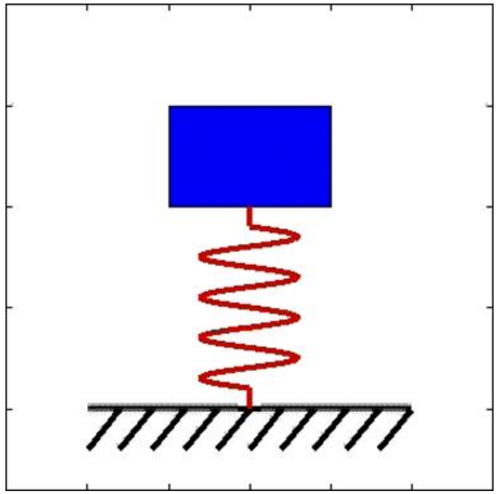


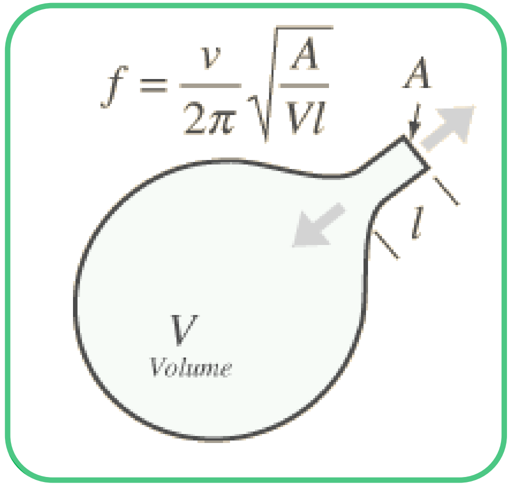
Herman von Helmholtz
1821-1894

Helmholtz Resonators



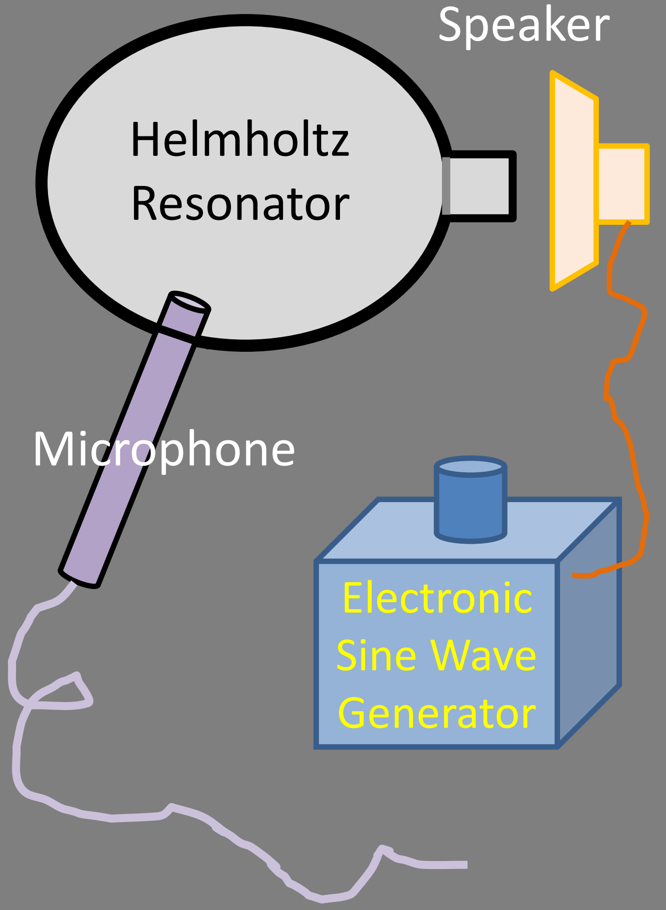
Simple Harmonic Oscillator





Helmholtz Resonator

147 Hz Resonance



Ever experience a Whump-Whump in your car when a rear window is cracked open?

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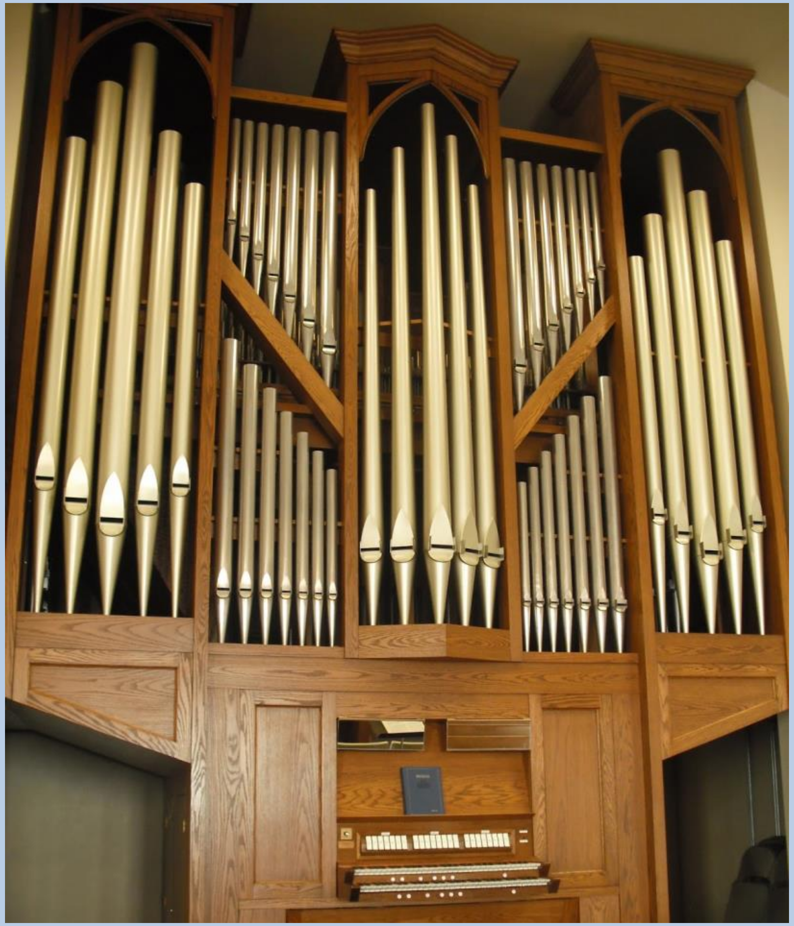
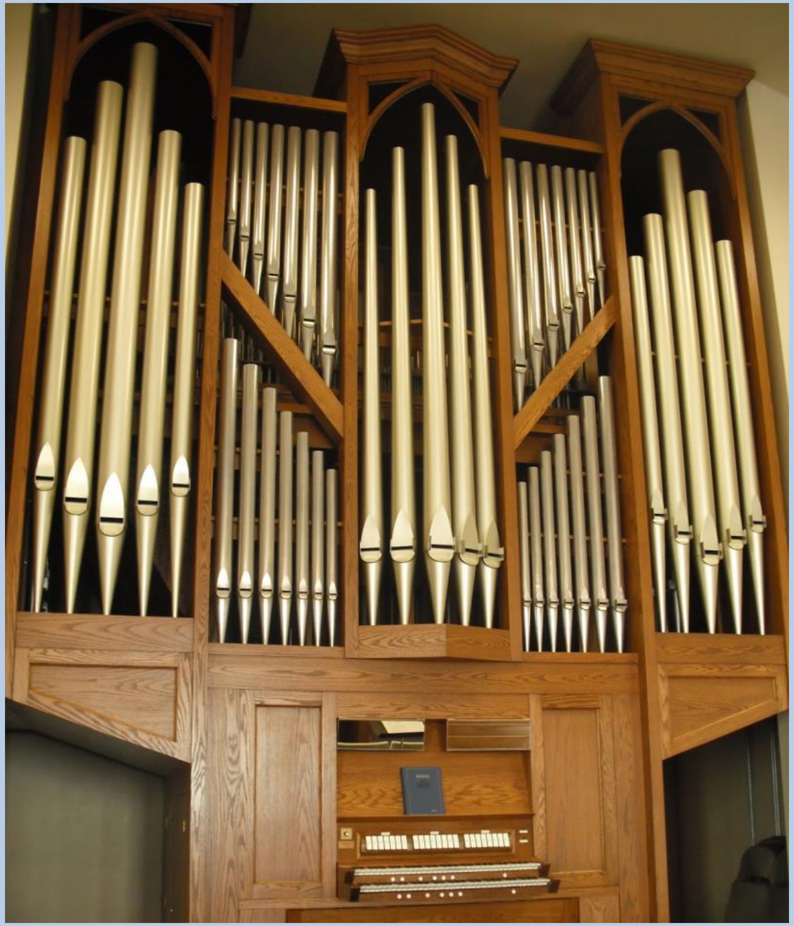
Resonators Using Strings and Pipes



Resonators Using Strings and Pipes

Anne Sullivan playing Siciliana (Respighi)



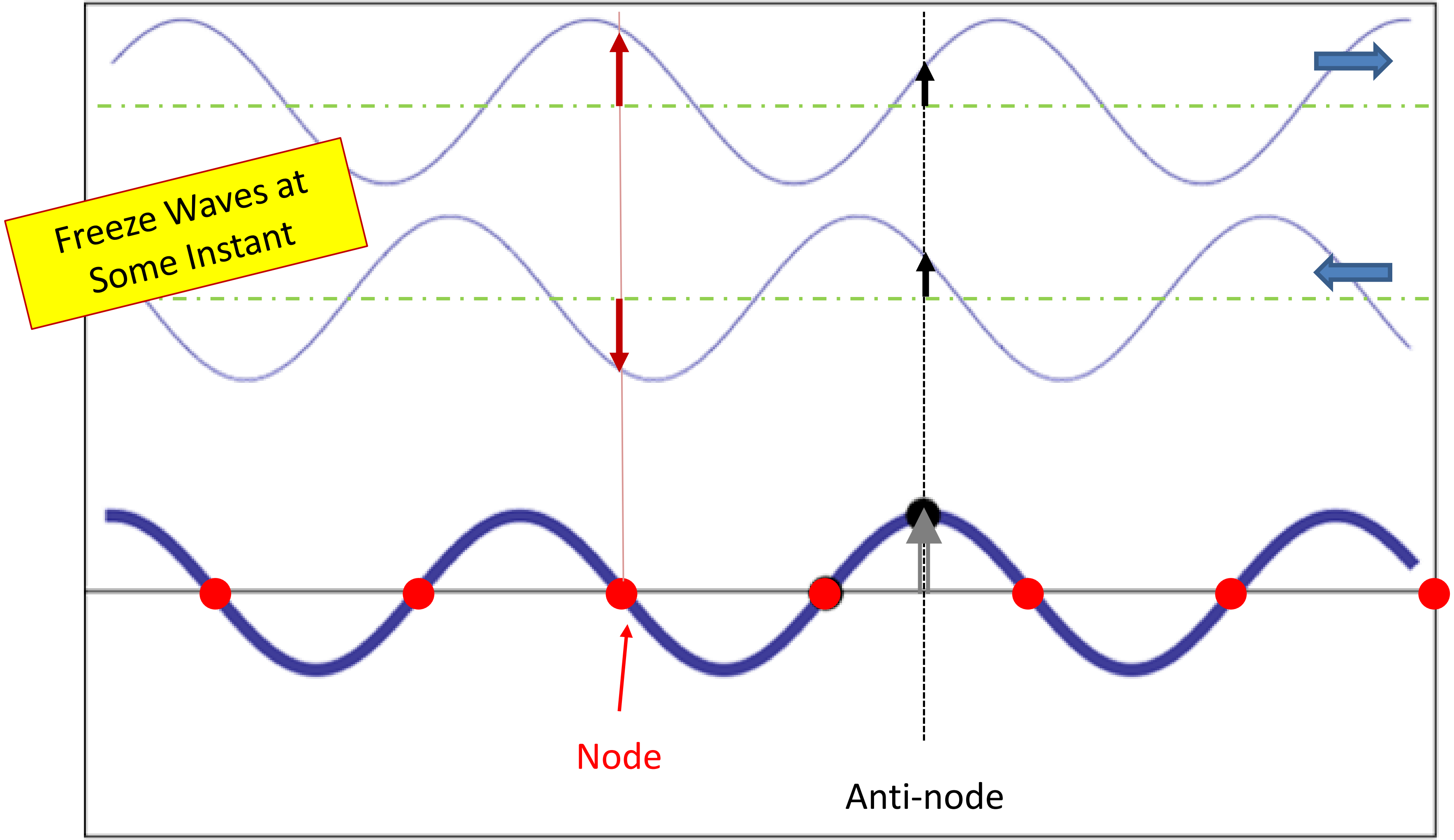
Resonators Using Strings and Pipes

Prelude in C Major (Bach): Brian of the LDS [Liahona.net]

Resonators Using Strings and Pipes

Easiest way to understand these is via the concept of "Standing Waves"

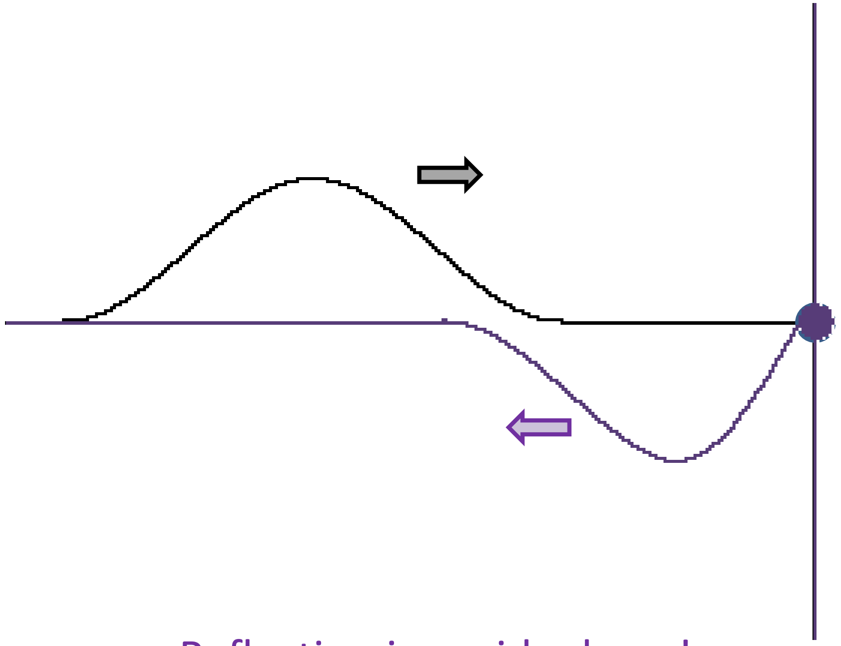
2 **Traveling** Waves Combine…
To Form a **Standing** Wave



Standing Waves in Air

Q: How Do We Make Standing Waves?

A: Reflections at a Boundary

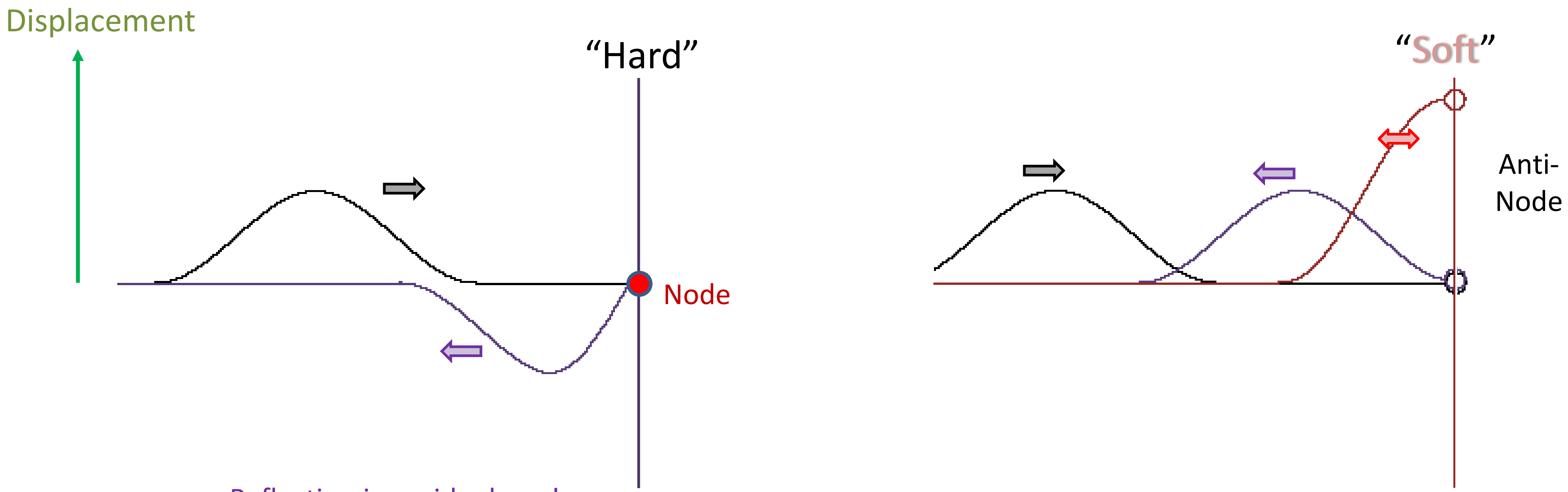


Reflection is upside down!

Reflection is ***not*** inverted!

Q: How Do We Make Standing Waves?

A: Reflections at a Boundary



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Q: How Do We Make Standing Waves?

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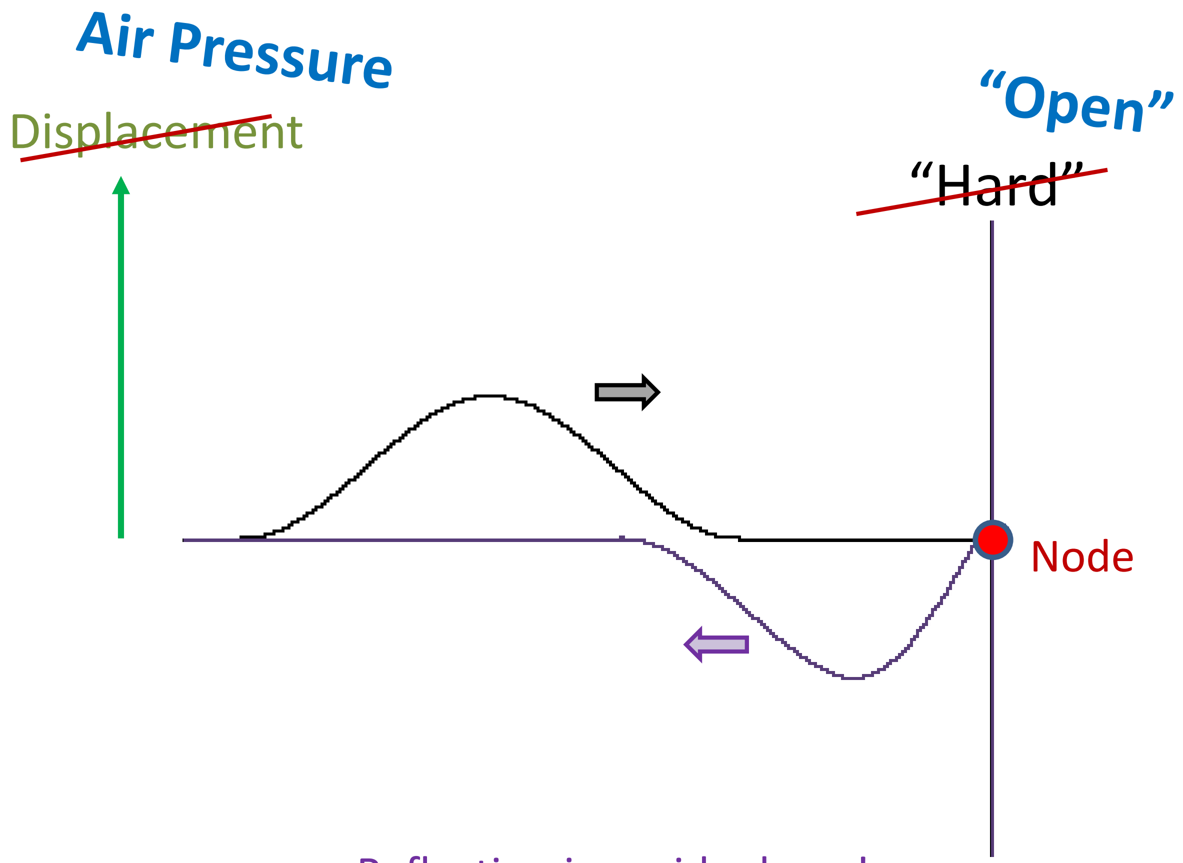

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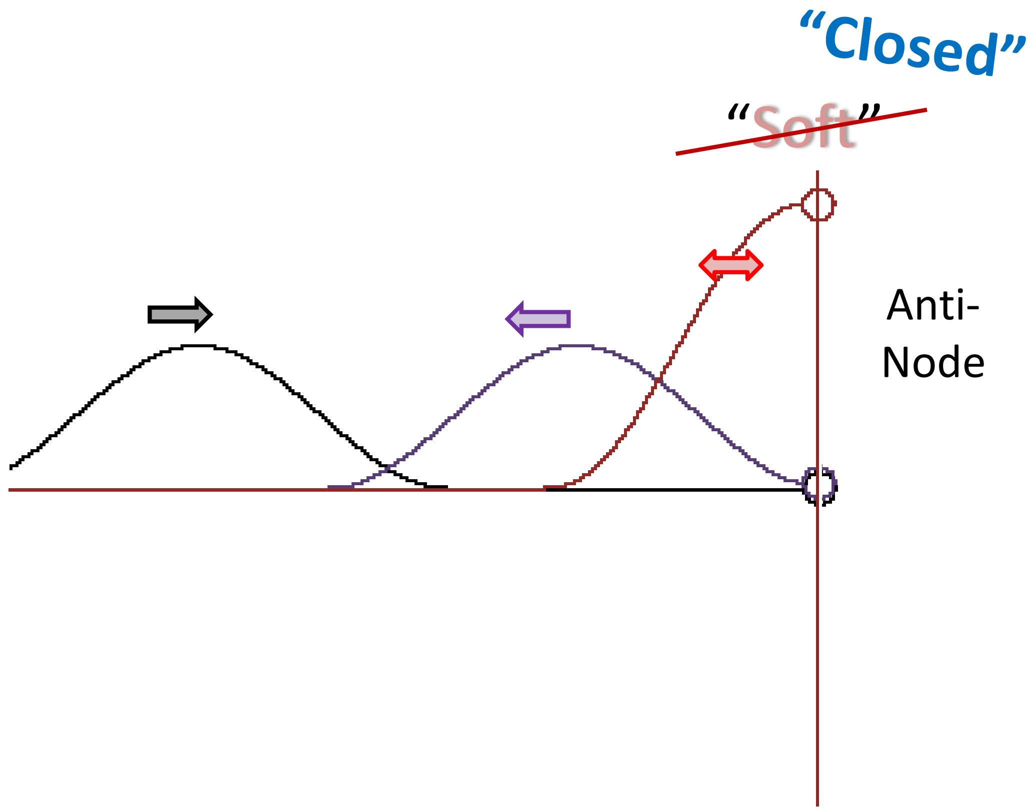
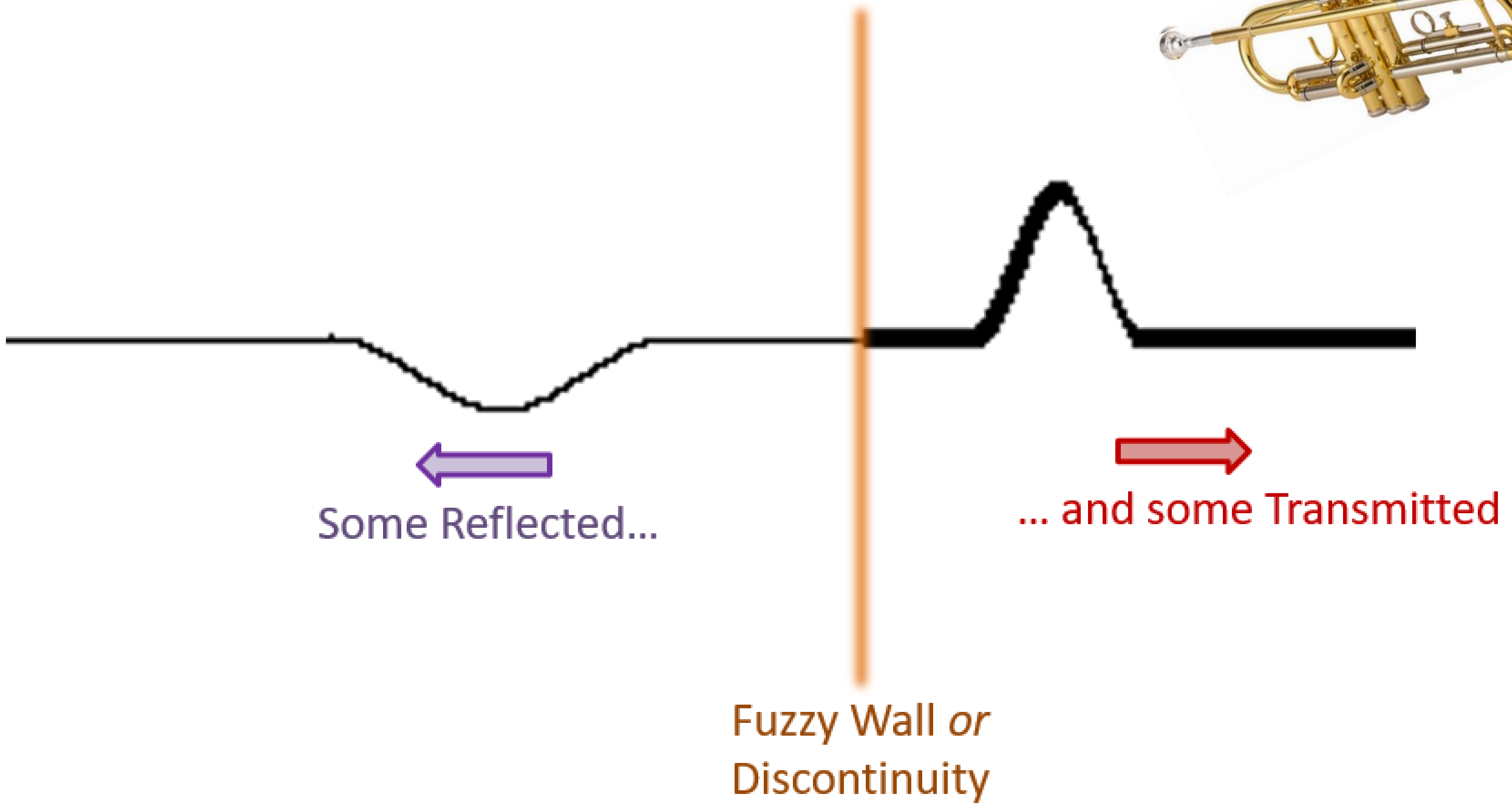


Reflection is ***not*** inverted!

Partial Reflection



The Monochord

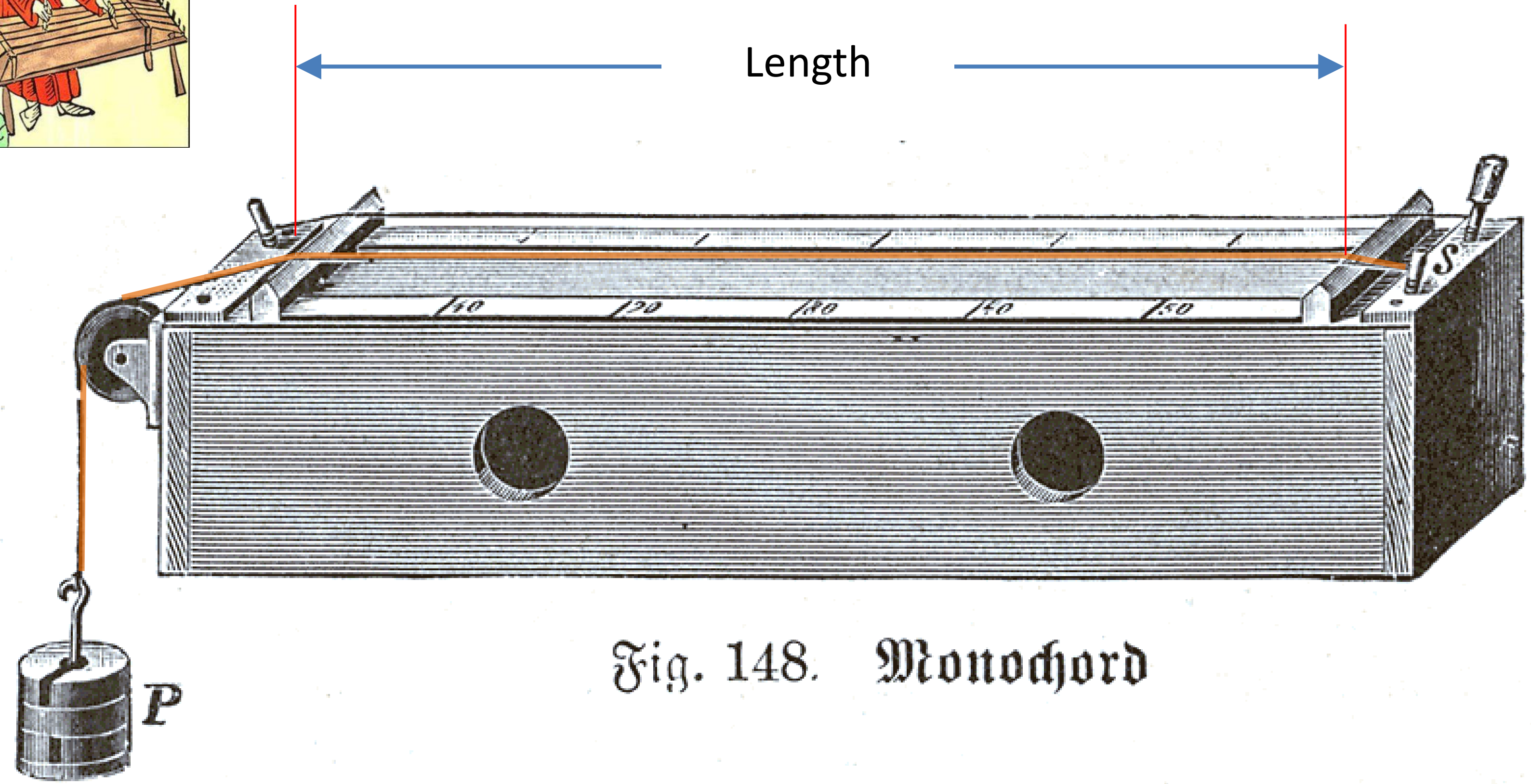
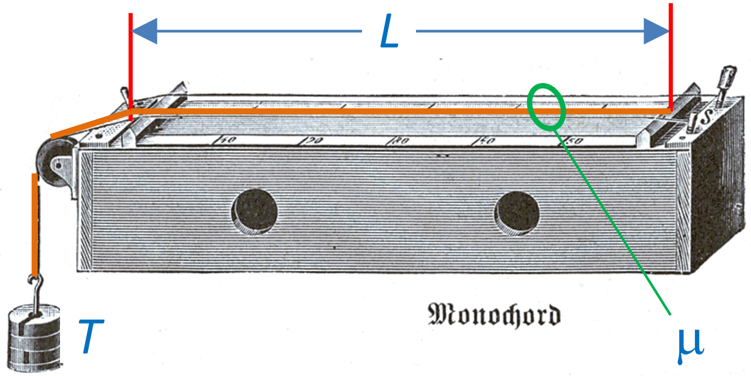


Fig. 148. Monochord

Mersenne’s Laws of Strings

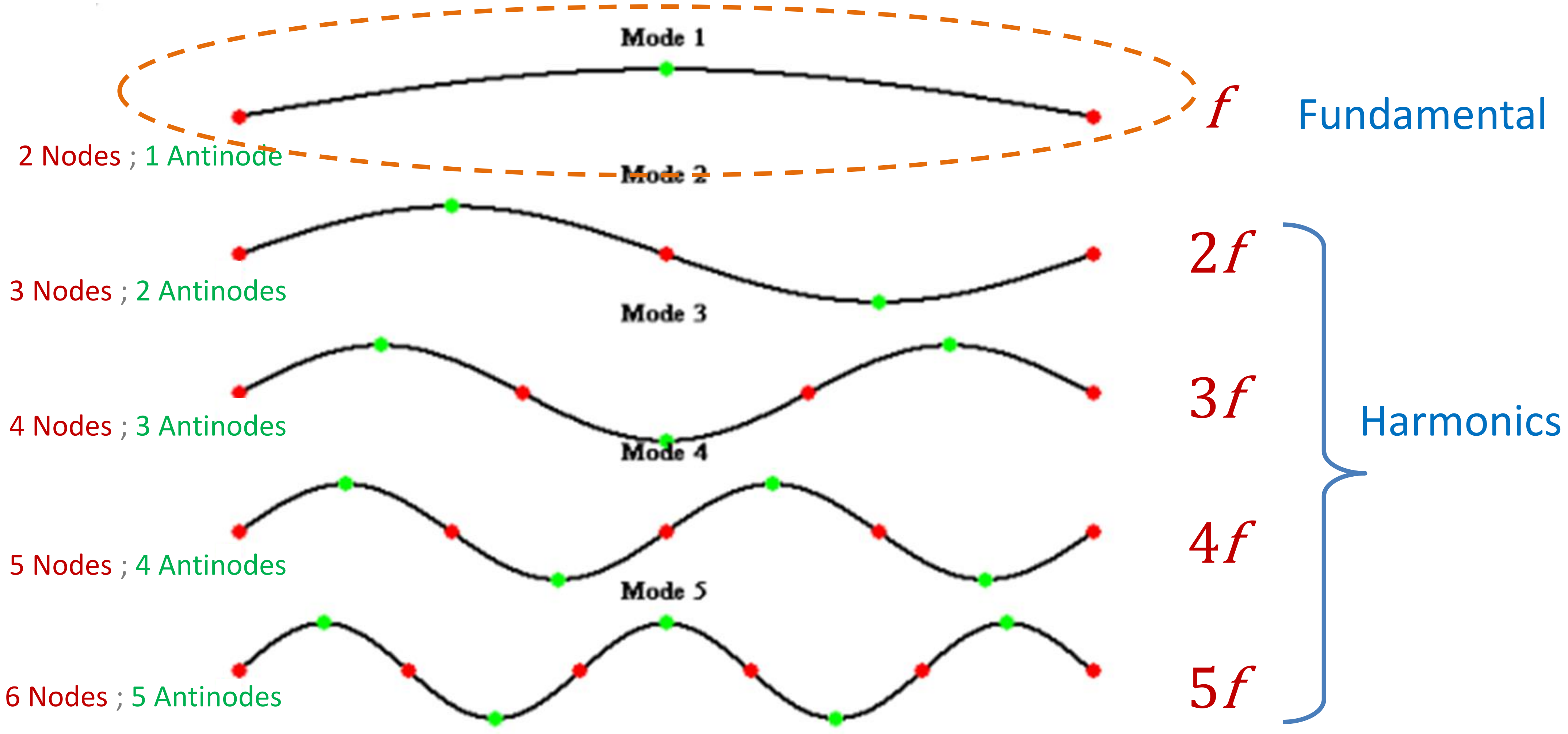
$$f_0 = \frac{1}{2L}\sqrt{T/\mu}$$



Frequency *f* depends on Length ***L***, Tension Force ***T***, and String Mass/length μ:

- $f_0 \propto \mathbf{1/L}$ inversely proportional to <u>length</u>
- $f_0 \propto \sqrt{T}$ proportional to *square root* of <u>tension</u>
- $f_0 \propto \mathbf{1/}\sqrt{\mu}$ inversely proportional to *square root* of <u>mass per unit length</u> (‘fatness’)

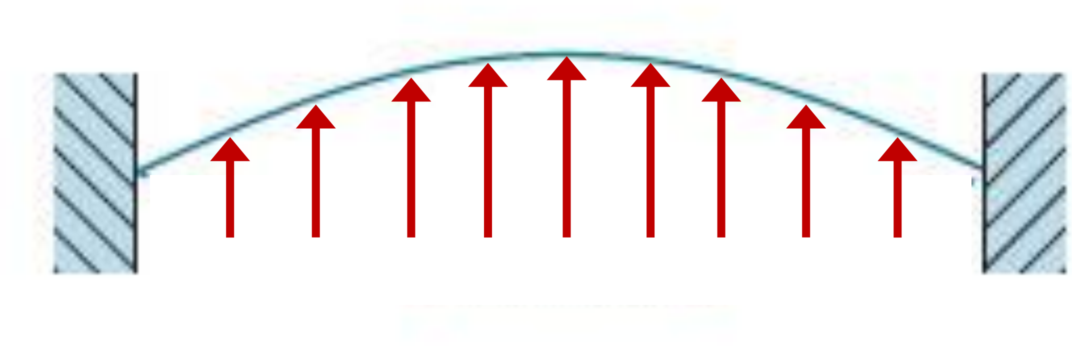
Possible Pure String Modes



IVSR

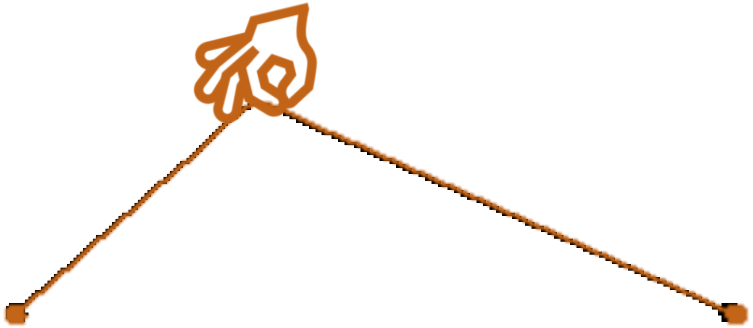
Try to Launch the Fundamental Mode:

Sine shape



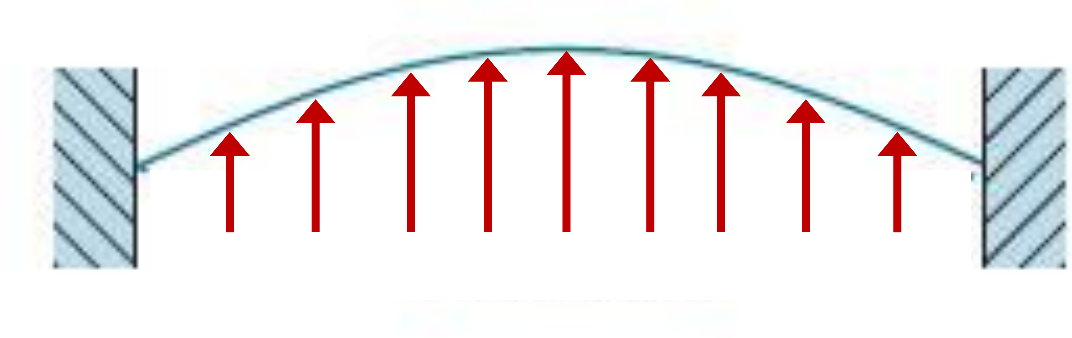
We could carefully pull the string into a half-sine wave and then suddenly let it go….

But we actually pluck a triangle …



Try to Launch the Fundamental Mode:

Sine shape



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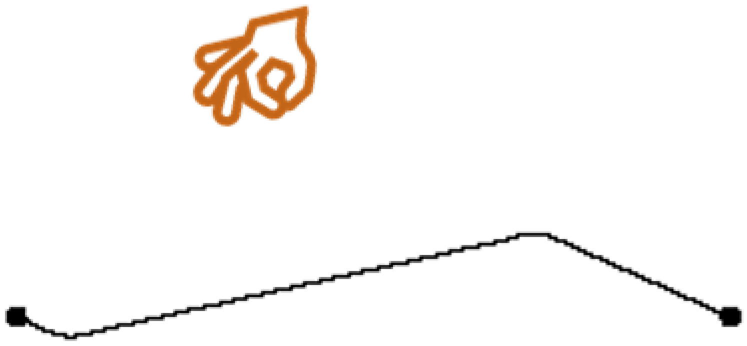
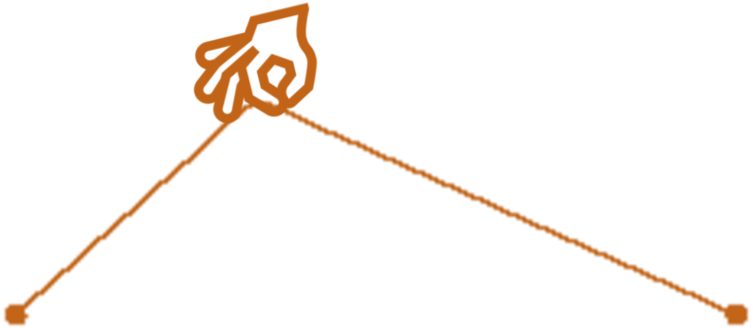


Many modes superimposed!

Try to Launch the Fundamental Mode:

Plucked String in Slo-Mo

Dan Russell, Kettering/Penn State (2011)



Many modes superimposed!

The First Electric Monochord?

Yuri Landman (YouTube 2011)

Tristan Andreas (YouTube 2012)

The Monochord

8 foot Electric
Monochord Demo

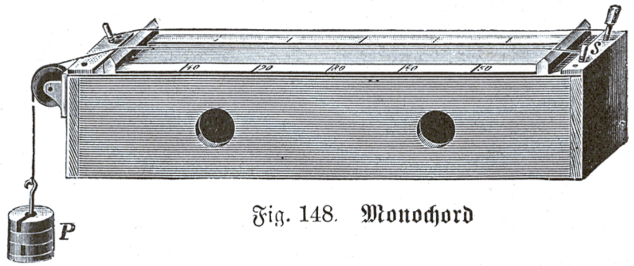
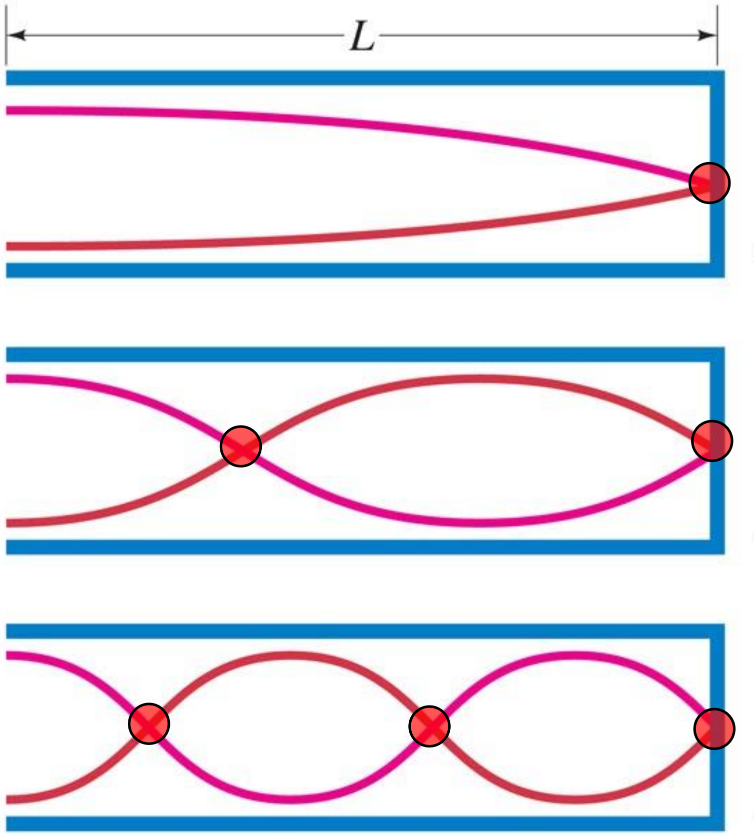


Fig. 148. Monochord

Organ Pipe – One Closed End

Air Displacement



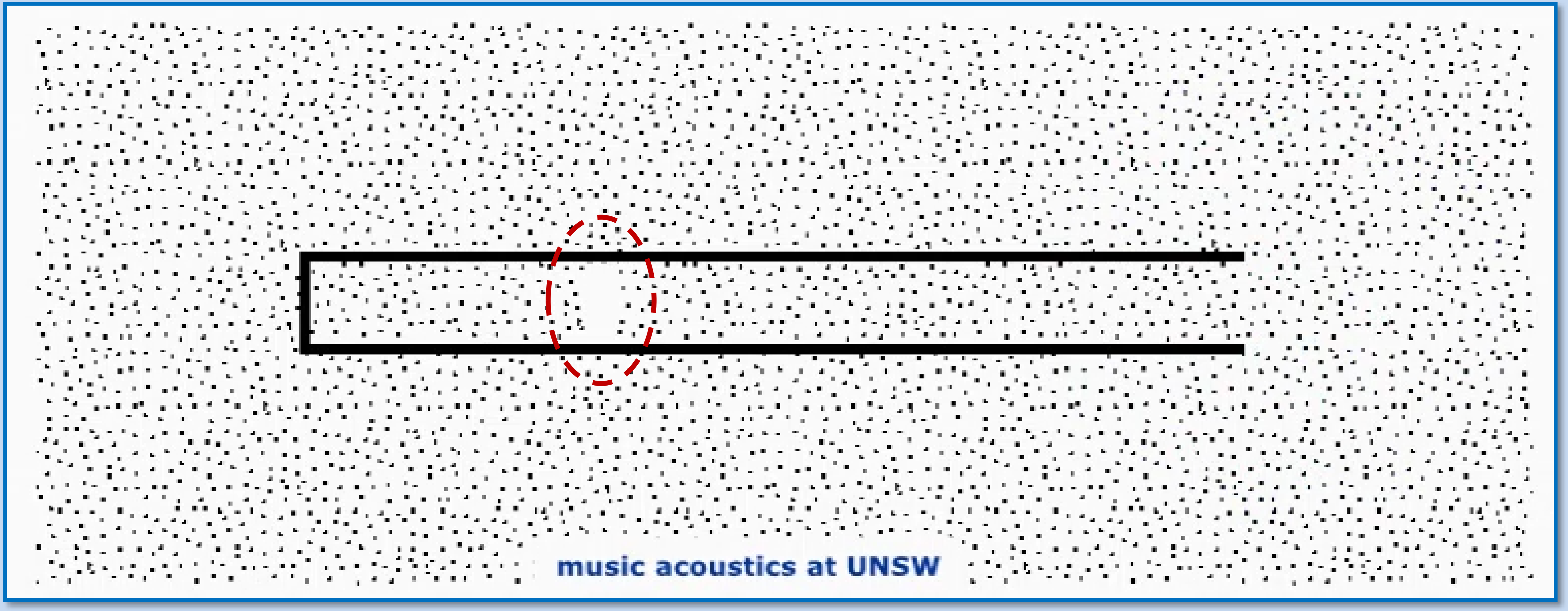
Fundamental Mode
$L = \lambda/4$

Third Harmonic
$L = (3/4)\,\lambda$

Fifth Harmonic
$L = (5/4)\,\lambda$

Standing Sound Waves in the Pipe

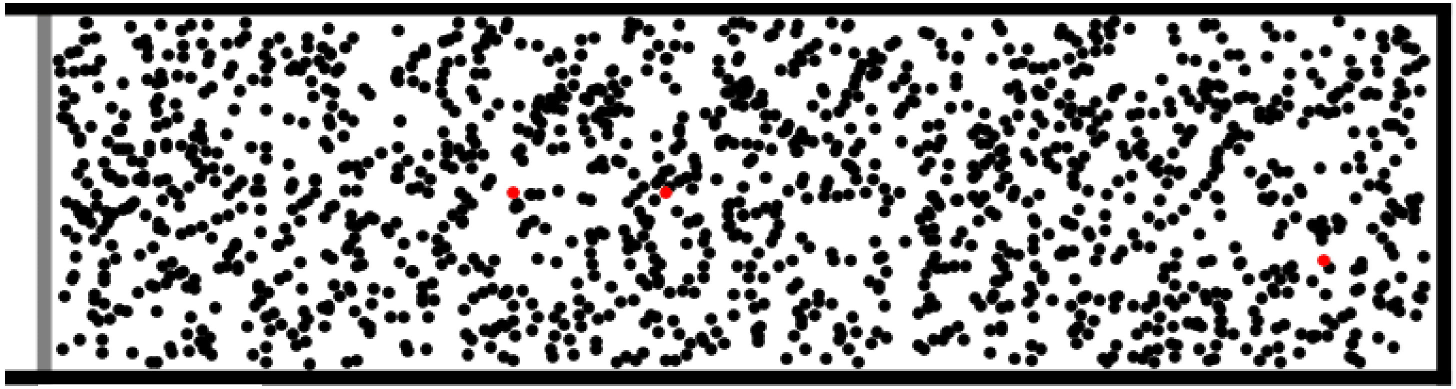
Illustration of Wave Reflection at Open End of Pipe



(Animation)

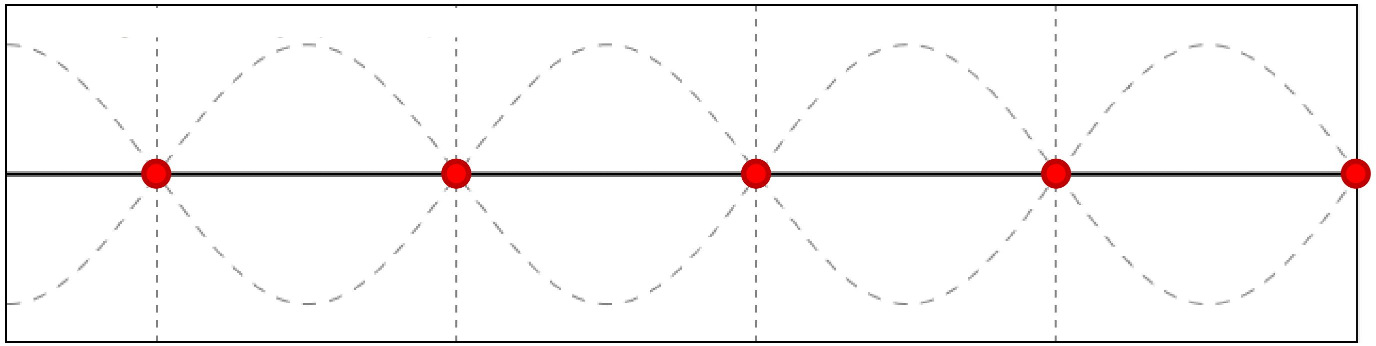
What's Actually Going On?

Open End of Pipe

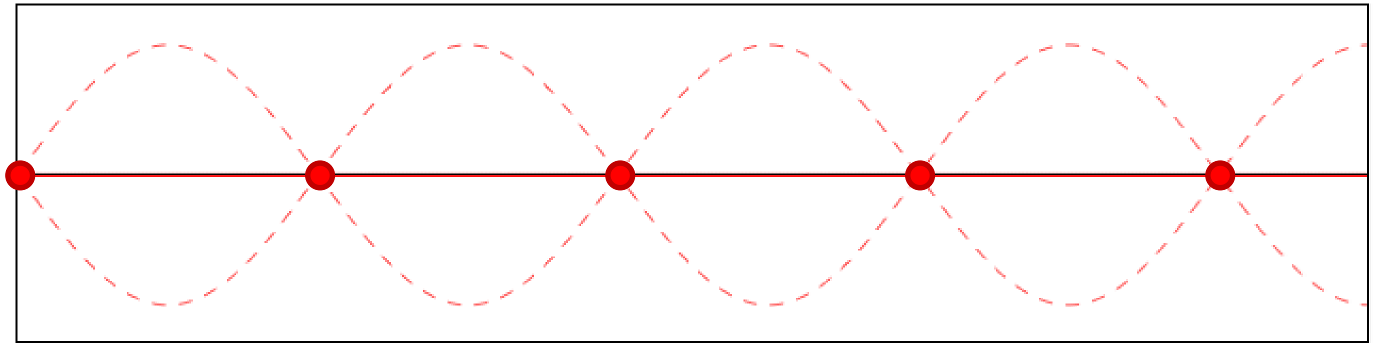


Open Organ Pipe: 9th Harmonic

Particle Displacement ↔

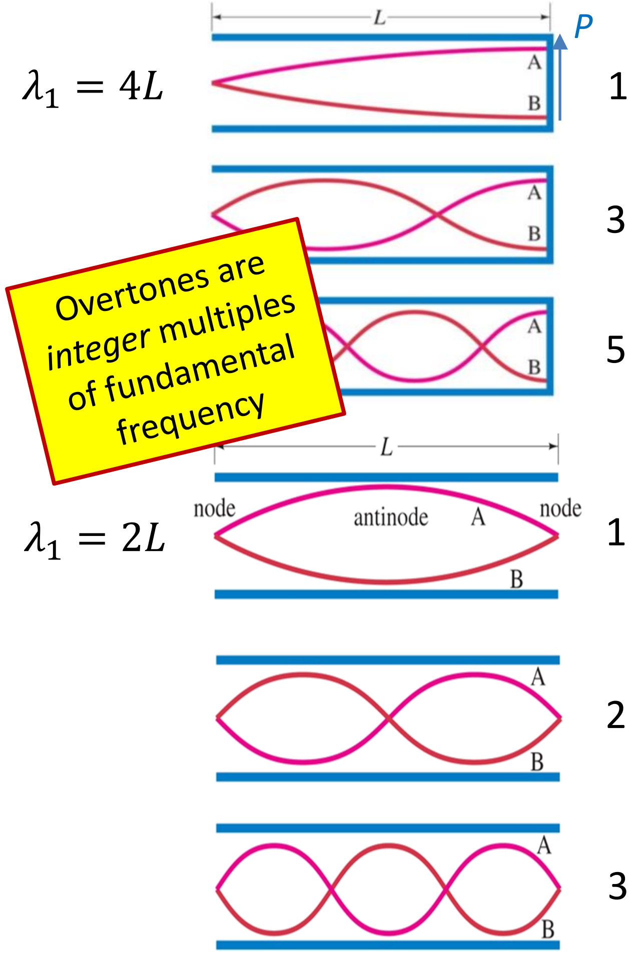


Pressure ⇕

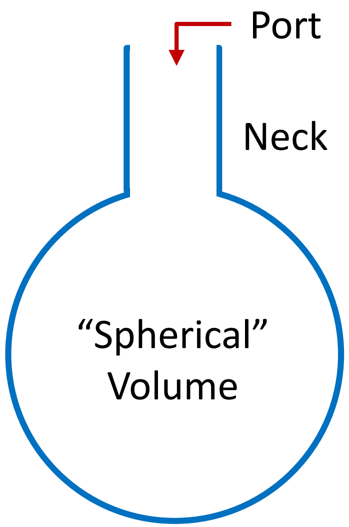


Resonant Cavities: Augmenting Sounds

Pipes

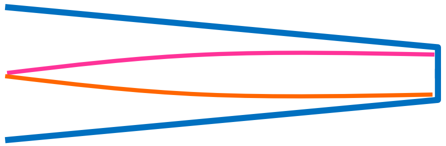


Helmholtz Resonators



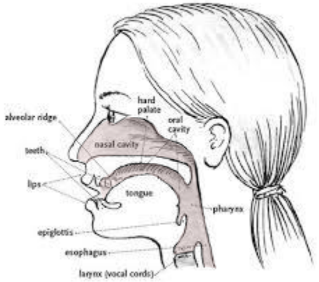
- Mainly has fundamental resonance
- Typically lower frequency than a pipe of similar length

Irregular Resonators



Non-uniform Pipe

- Overtones *not* integer multiples unless conical
- *Example:* Saxophone



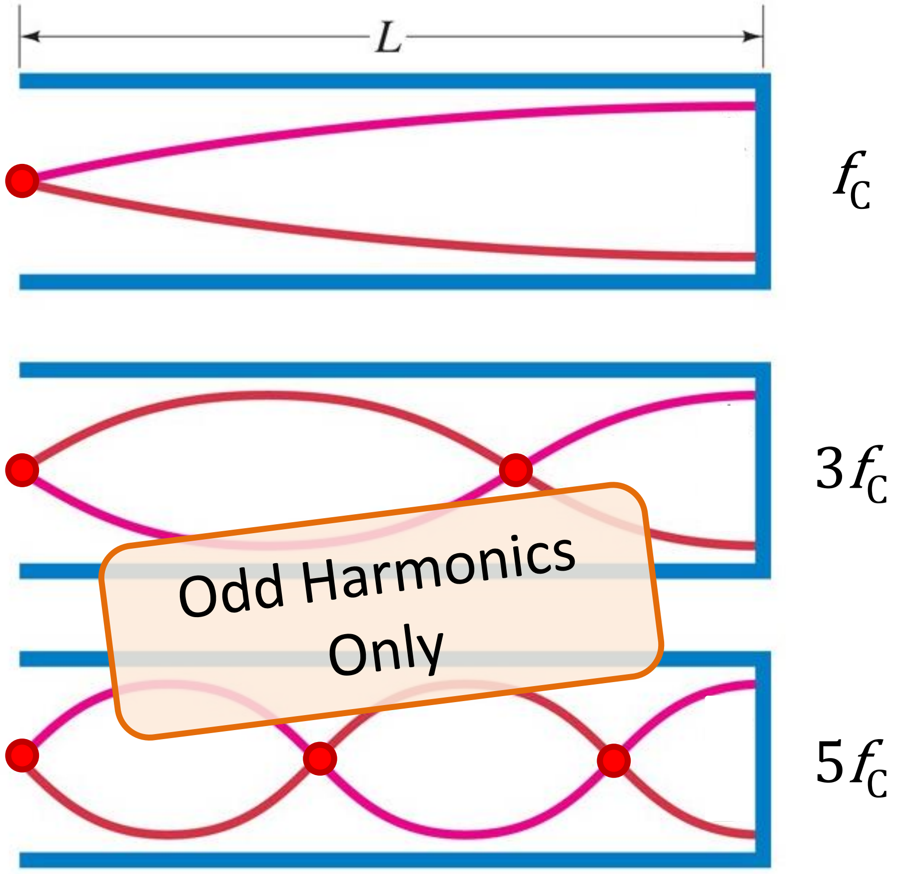
Closed vs. Open Pipe (*Pressure Modes*)

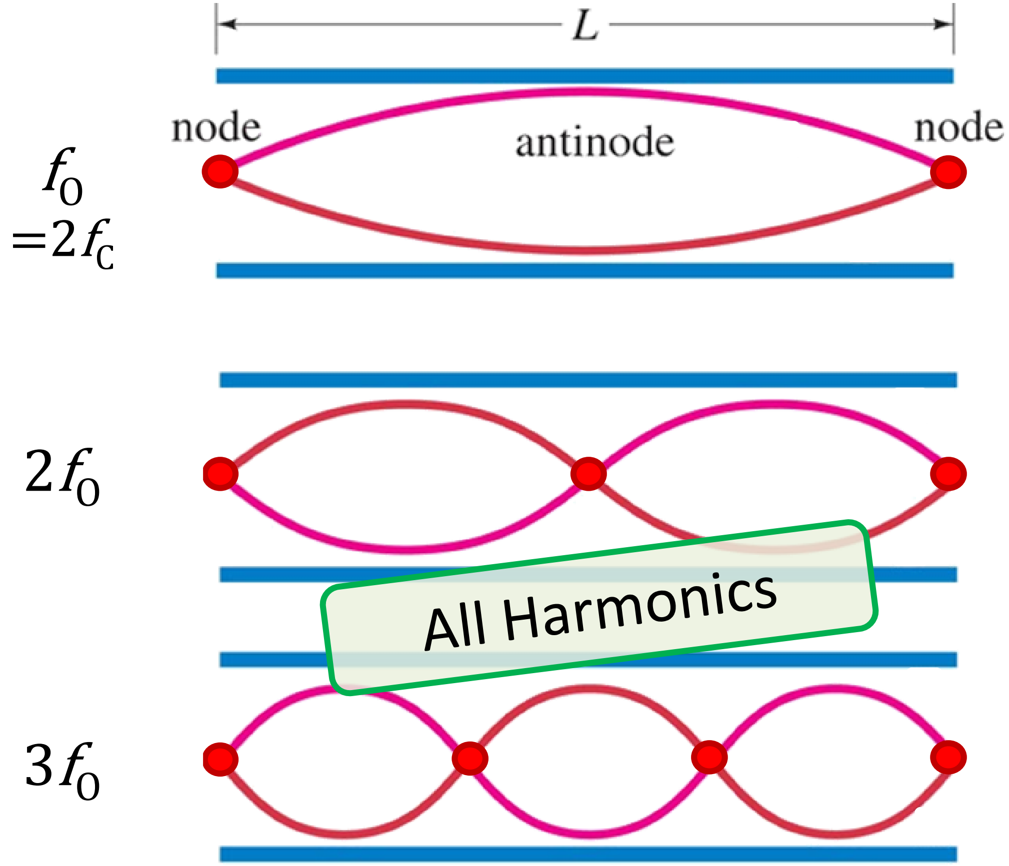
Closed One End

Clarinet , e.g.

Open Both Ends

Flute, e.g.

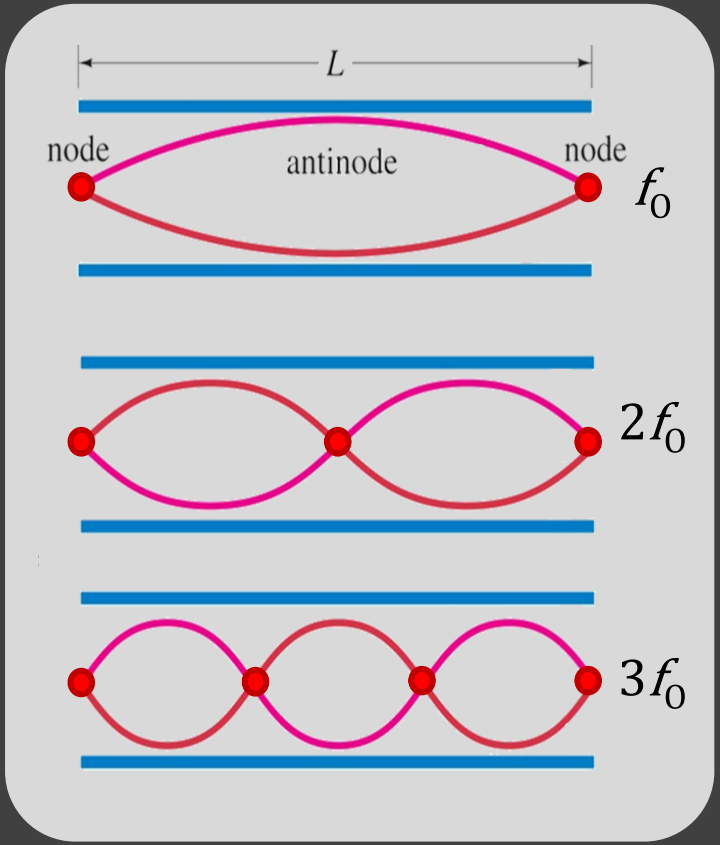




Open Pipe

≈5.6 ft

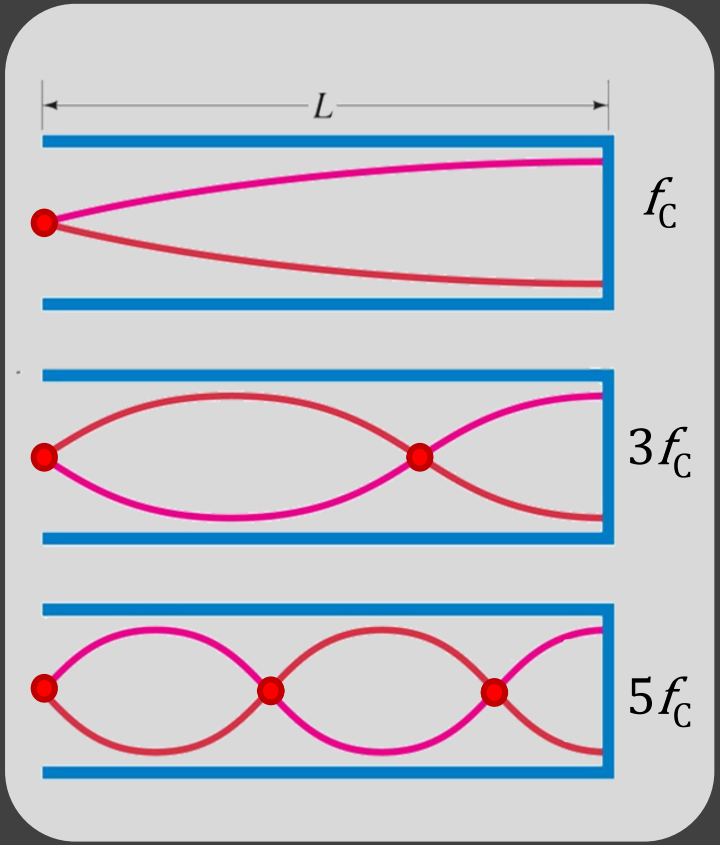
Demo



Closed Pipe

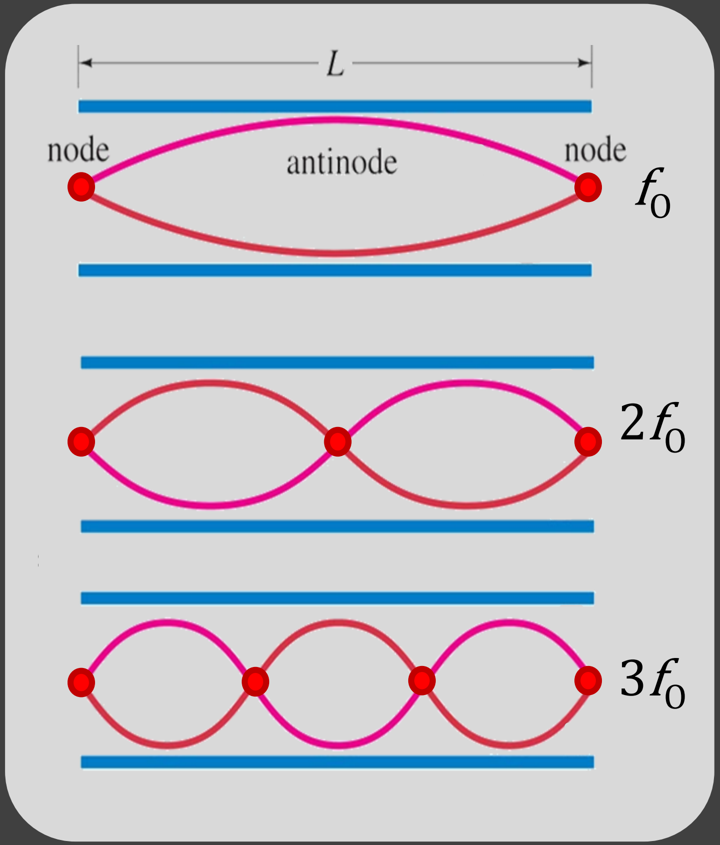
≈5.6 ft

Demo



Open Pipe
(Bent 4.7ft)

Demo: Not Carried Out



This is as far as we got.....

Air Column Instrument Examples

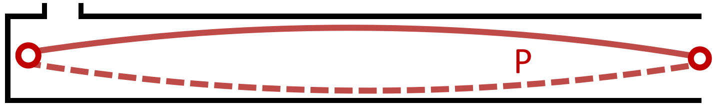
Open Cylinder

Flute

Air Column Instrument Examples

2 ft

Open Cylinder

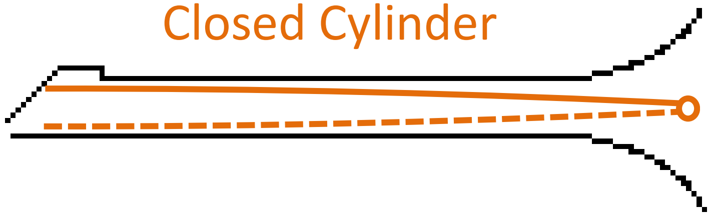


½ wave

Flute

$\lambda_o \approx 4$ ft

Closed Cylinder

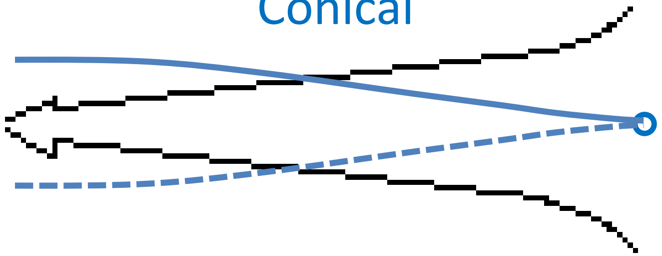


¼ wave

Clarinet

$\lambda_o \approx 8$ ft

Conical

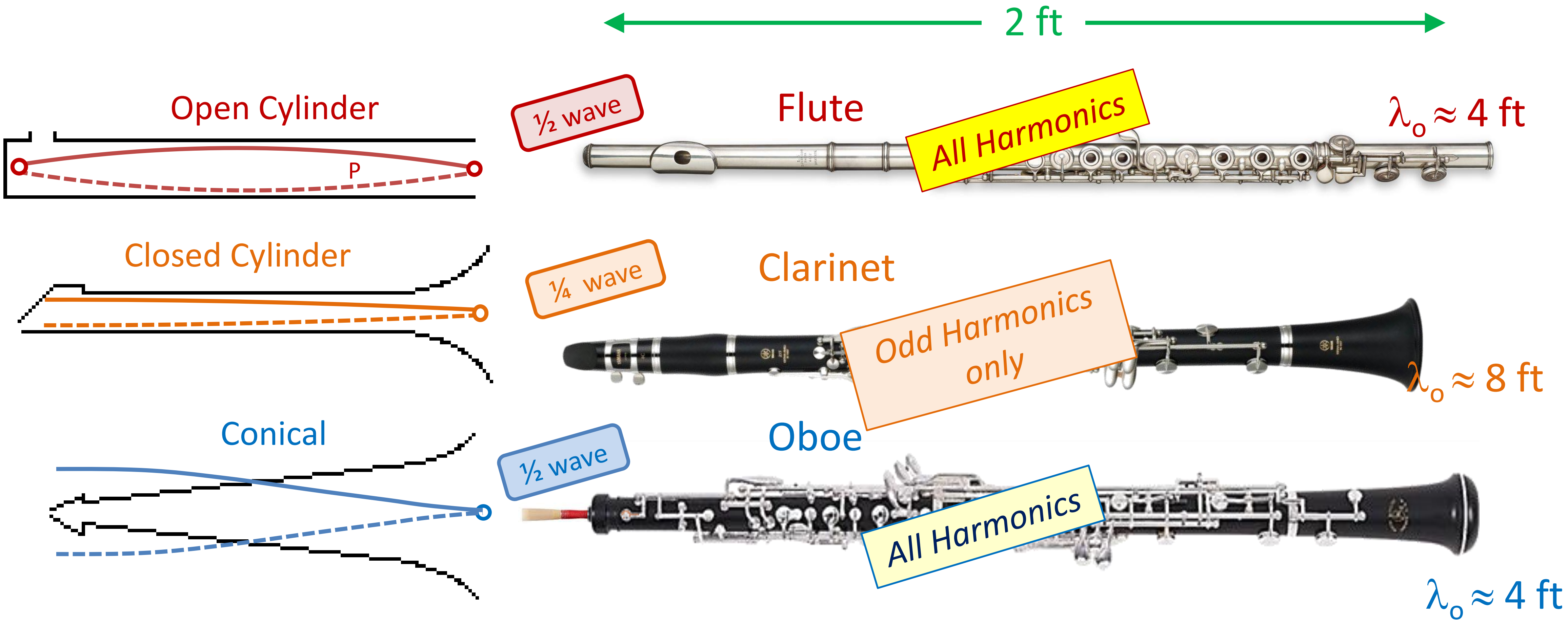


½ wave

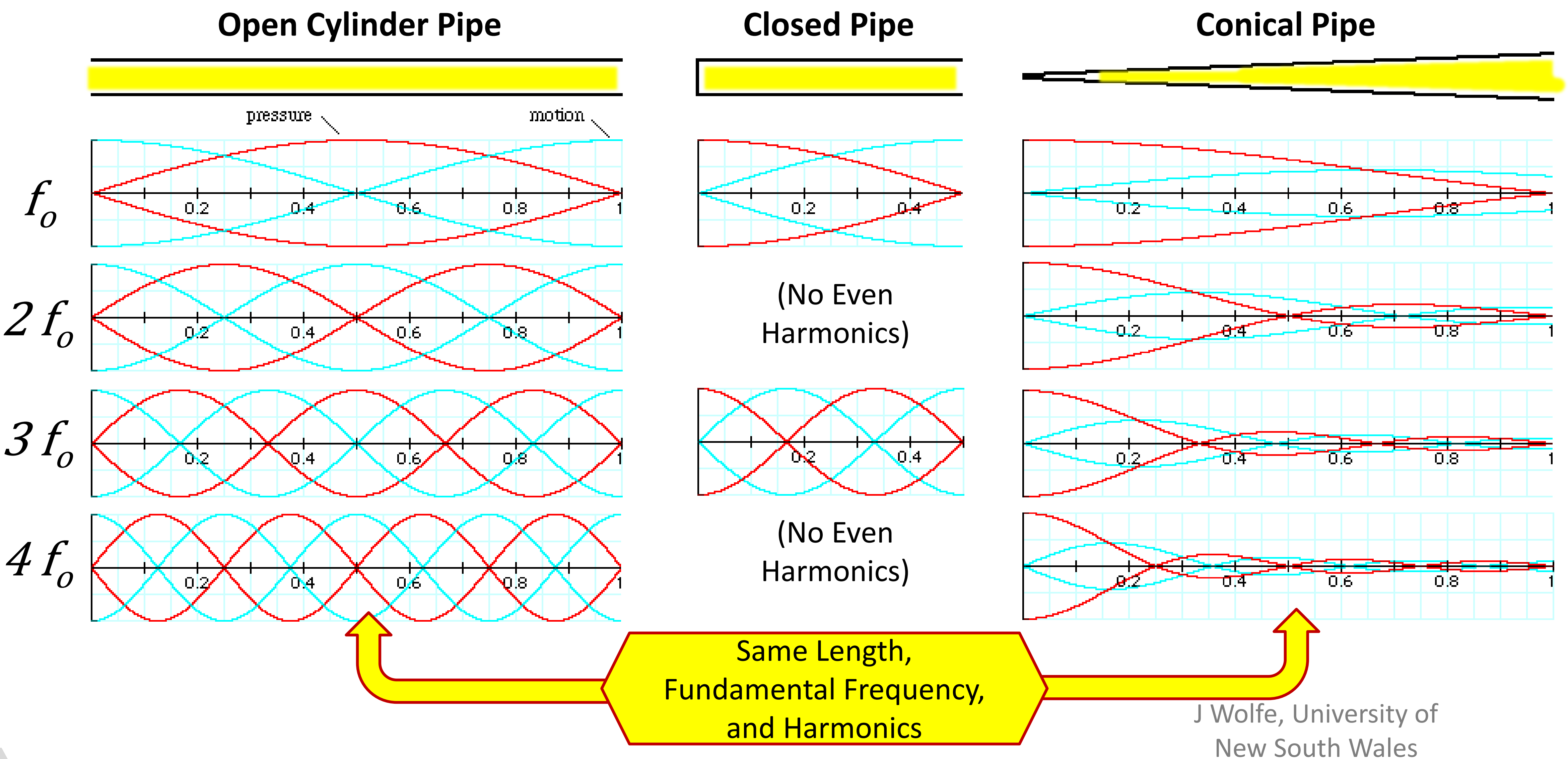
Oboe

$\lambda_o \approx 4$ ft

What About Timbre?



Comparison of Standing Wave Modes

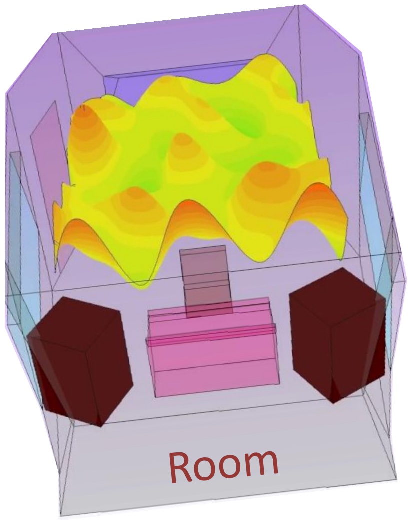


J Wolfe, University of New South Wales

More Complex Resonators





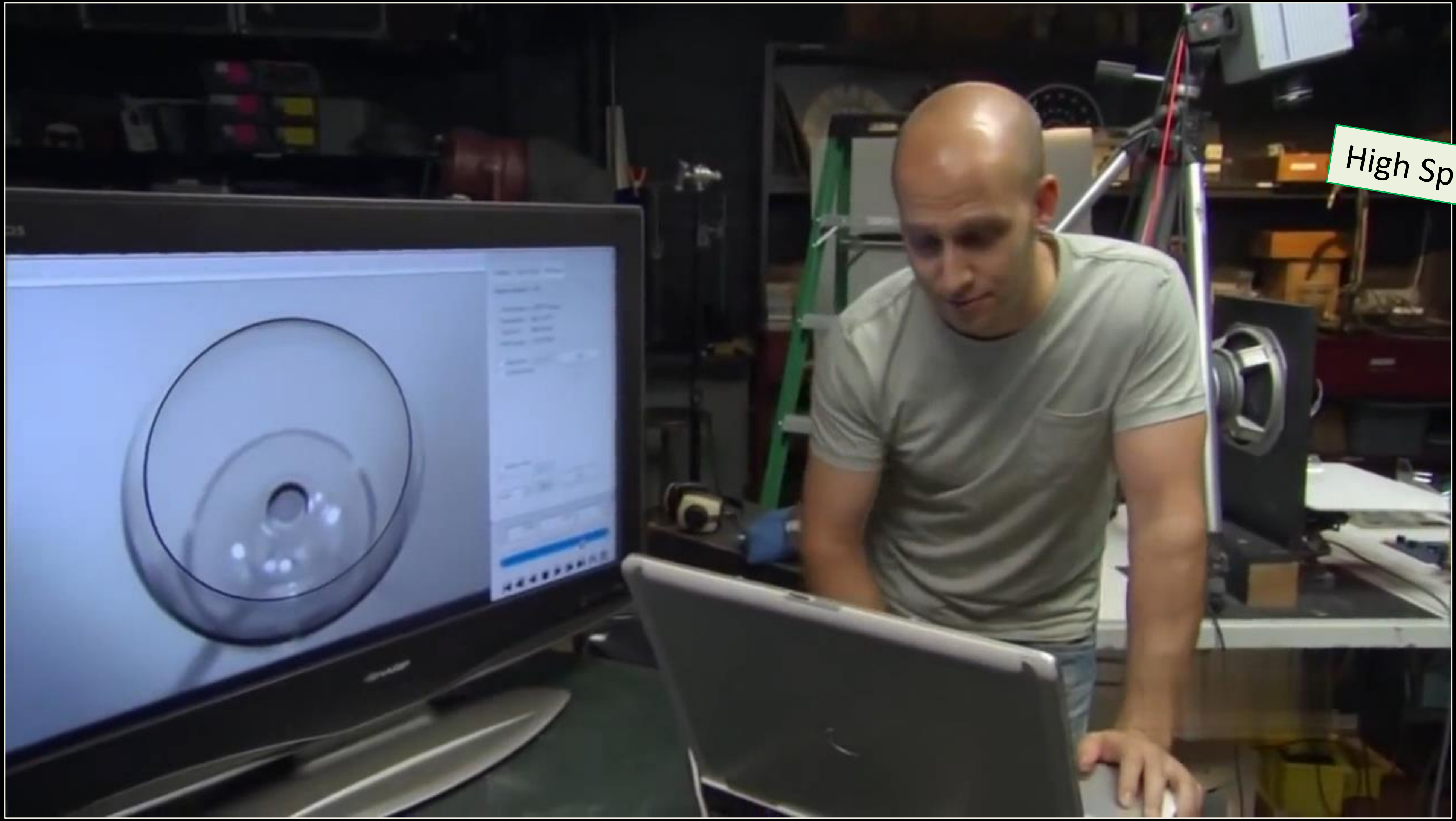


Common Characteristic:

Modes are generally *not* harmonics of Fundamental

Singing Prayer Bowl

Resonant Vibrational Modes of a Wine Glass



Marty33 2009 YouTube
Wine Glass Resonance in Slow Motion

Benjamin Franklin's Glass Harmonica (1761)

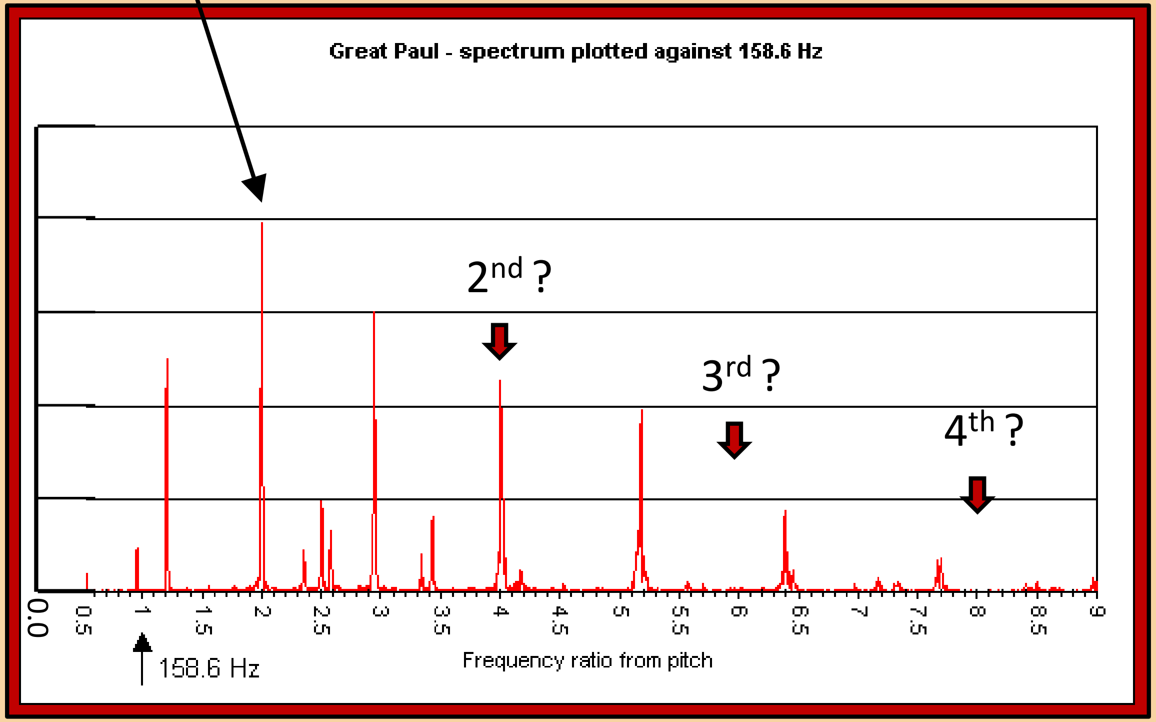
Stick/Slip on rotating glass bowls

Thomas Bloch, Paris Music Museum 2007

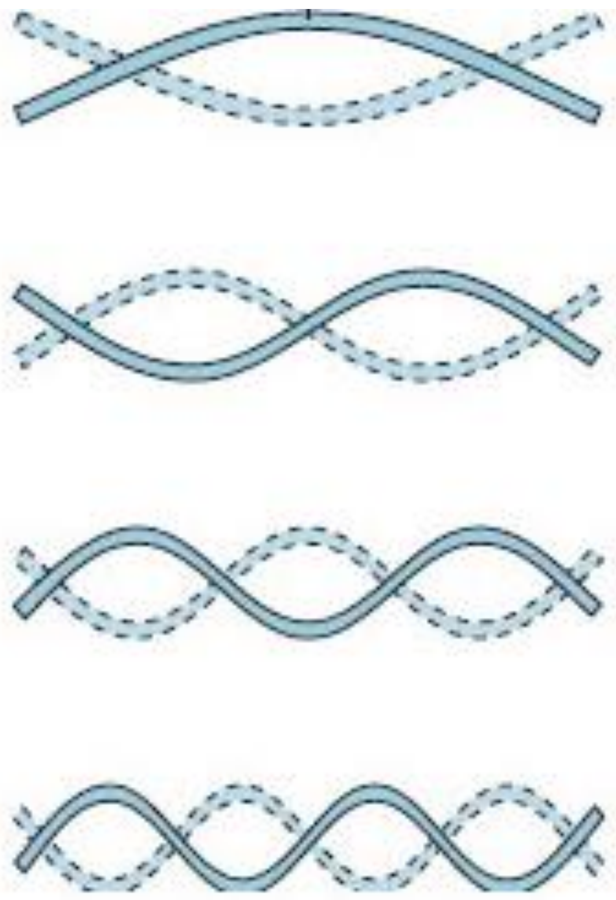
Great Paul Bell
St. Paul's Cathedral

1882, 17 tons

Apparent Frequency:
317 Hz



Vibrating Bars



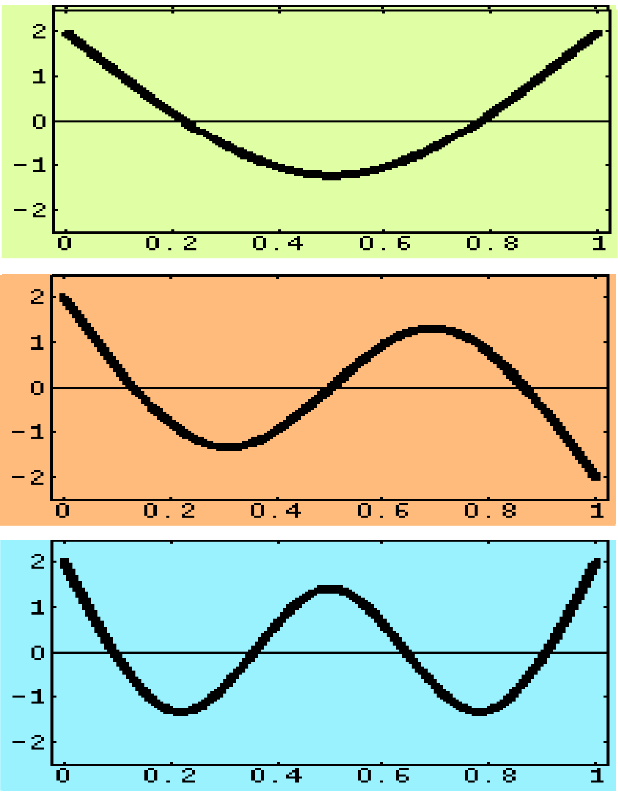
f_0

$2.76\ f_0$

$5.40\ f_0$

$8.93\ f_0$

Open University [GB]

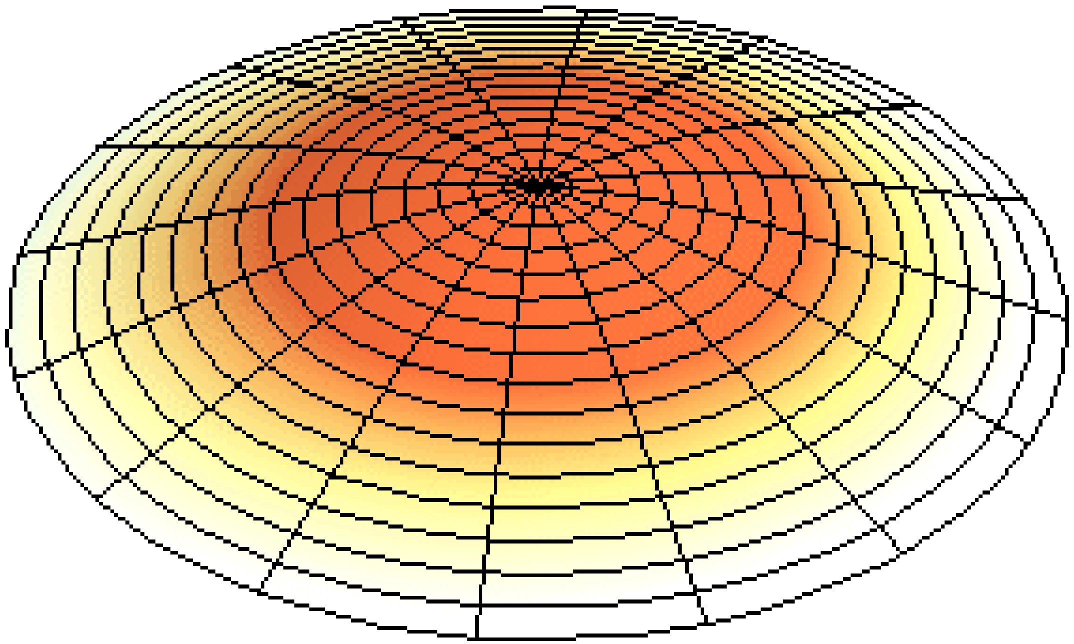


Dan Russell
(Penn State)

Not anywhere near harmonic!

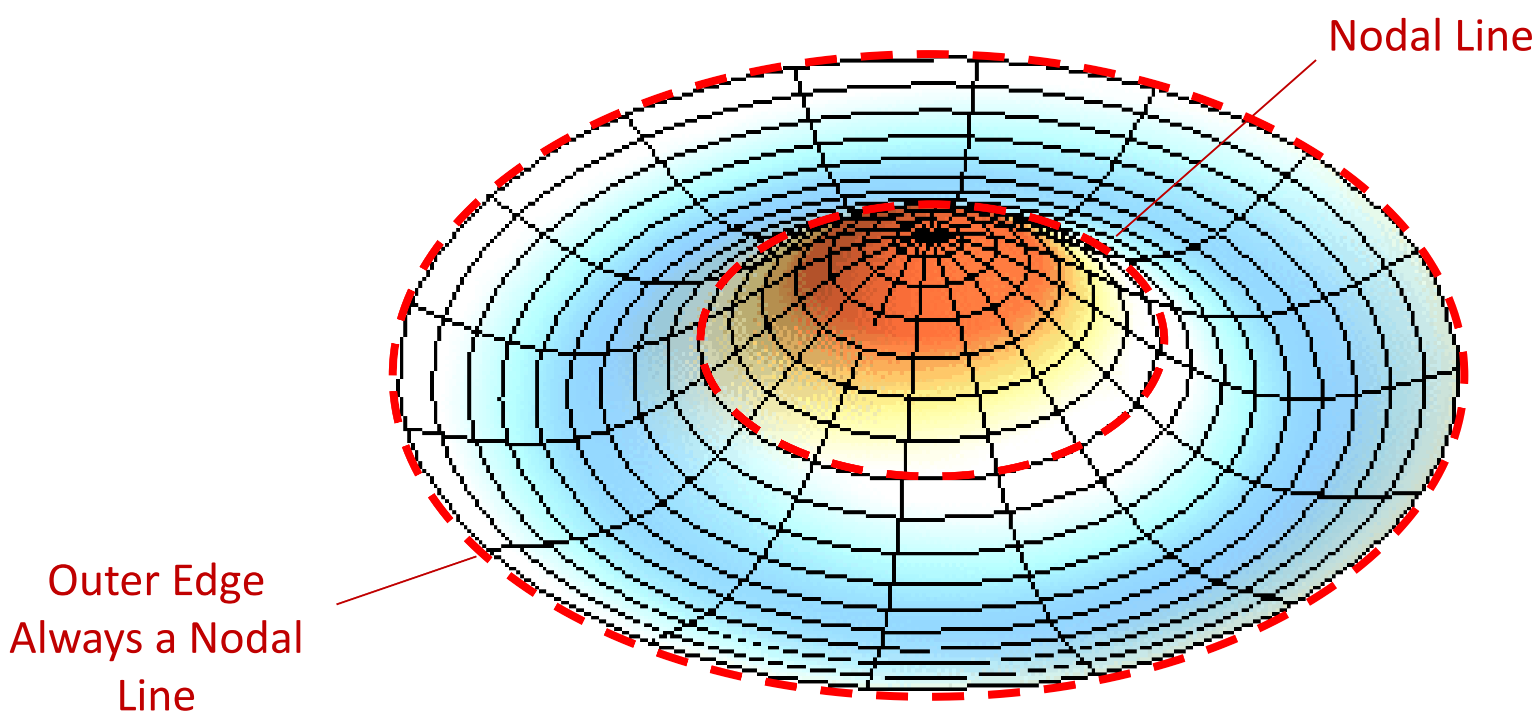
Drumheads:
Two Dimensional Membranes

Fundamental Mode of a Drumhead (0,1)



D Russell Penn State

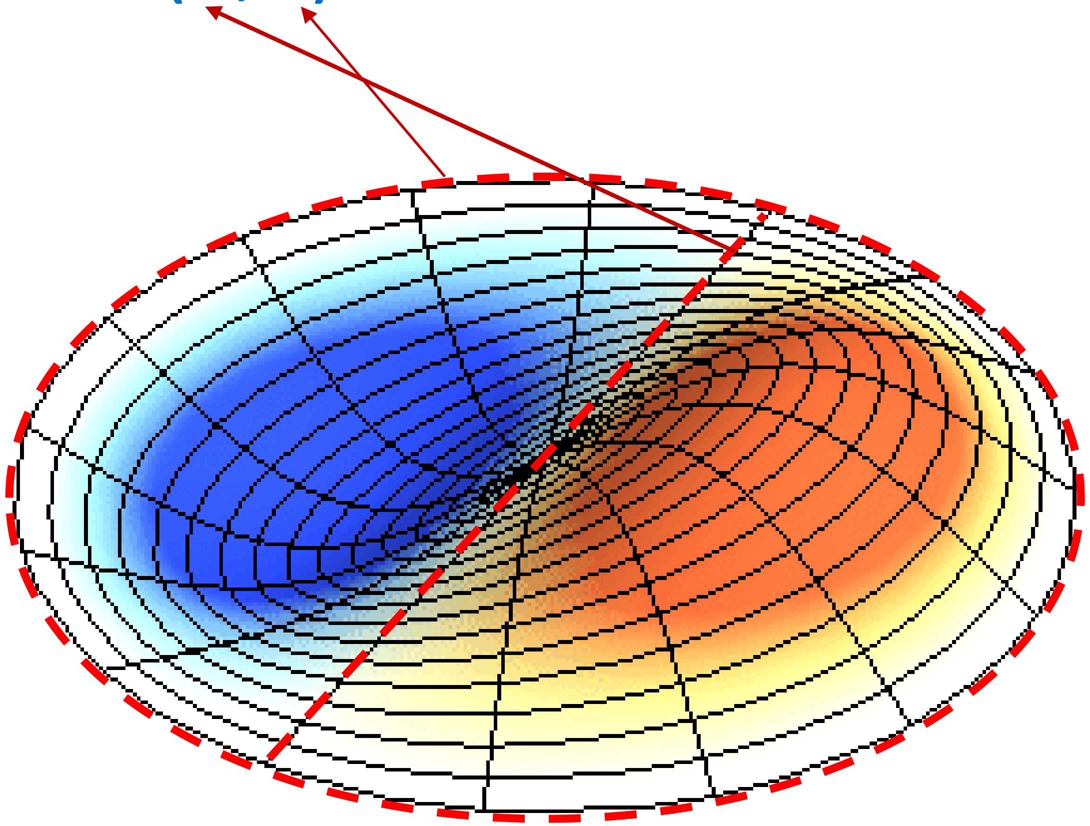
The (0,2) Drumhead Mode



$f = 2.295 \, f_0$

D Russell Penn State

The (1,1) Drumhead Mode

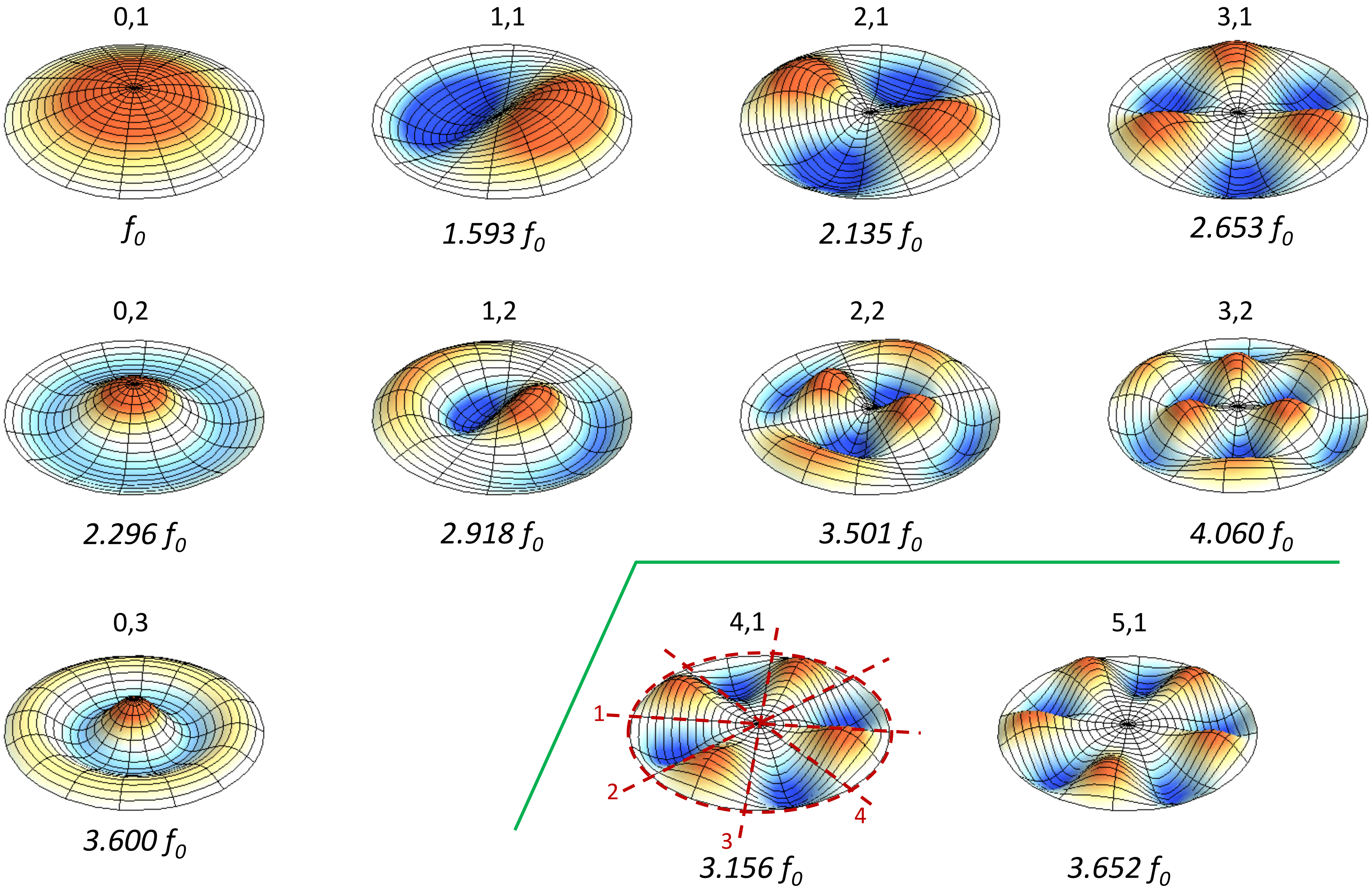


Symmetric:
No net air volume
change under the
drumhead

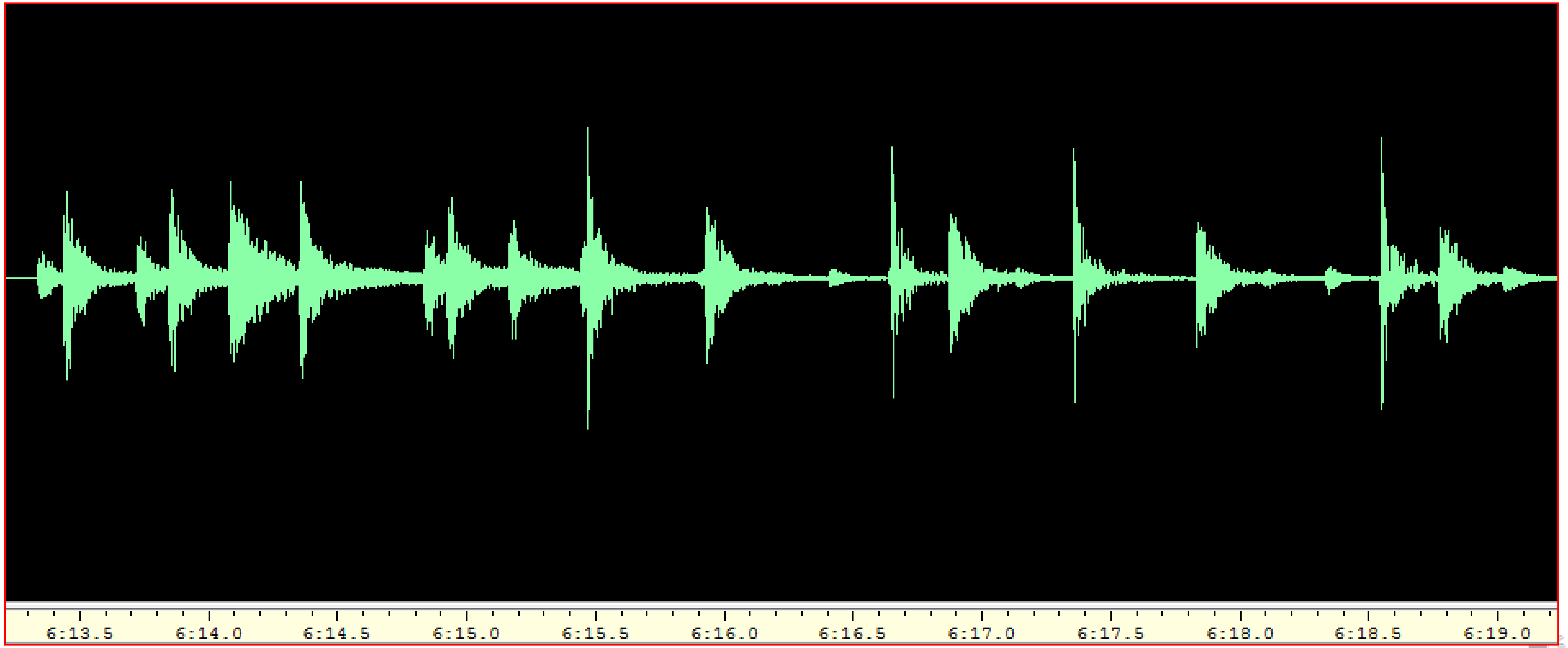
$f = 1.593\, f_0$

D Russell Penn State

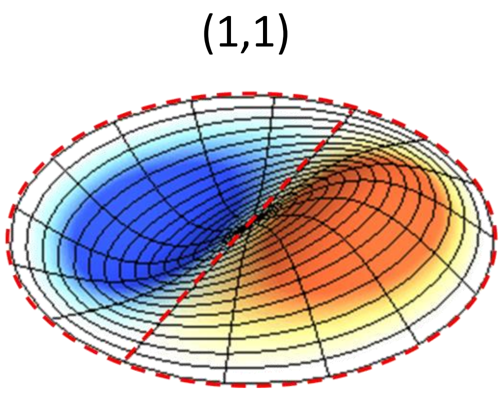
More Drumhead Modes



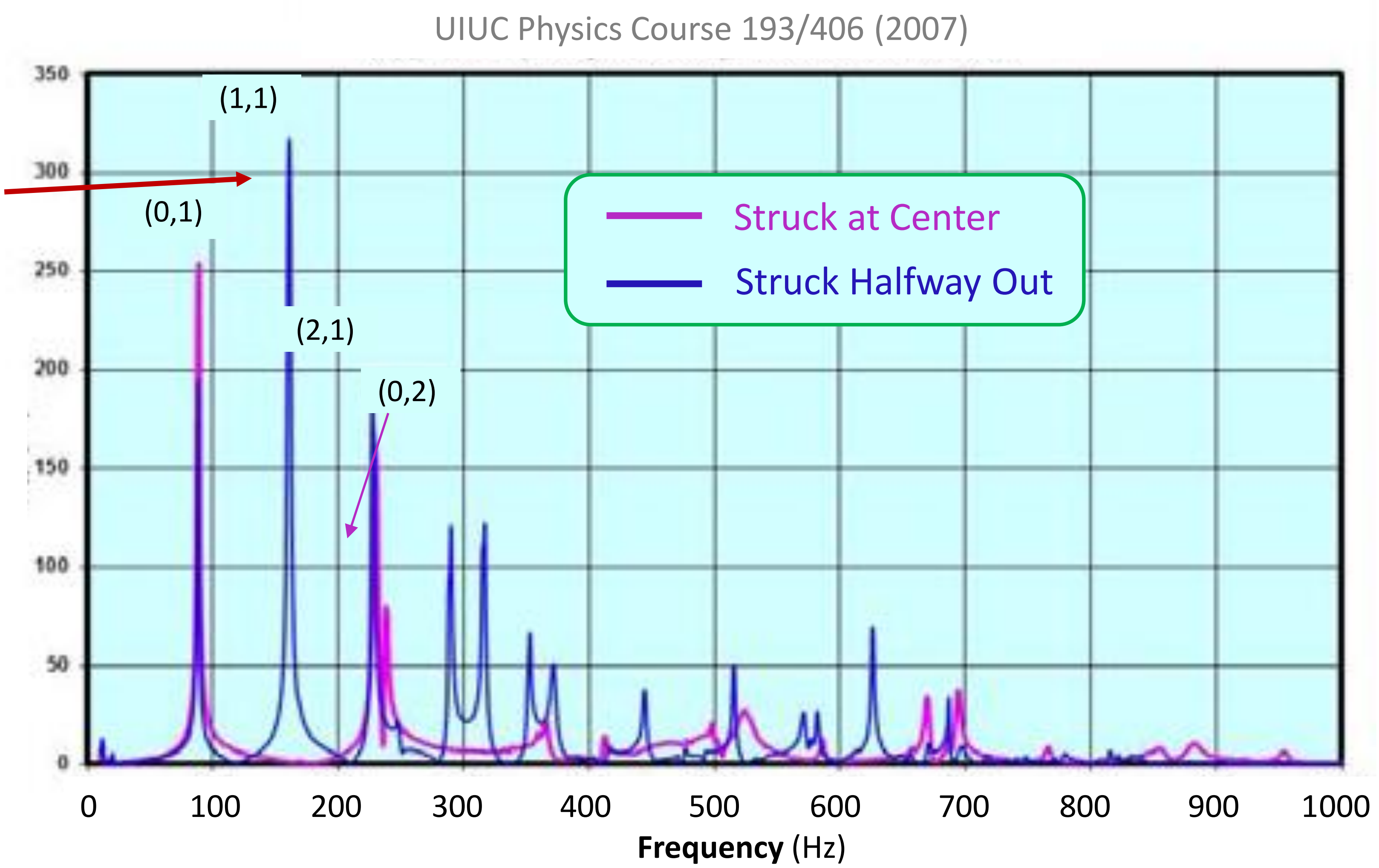
What you're hearing…



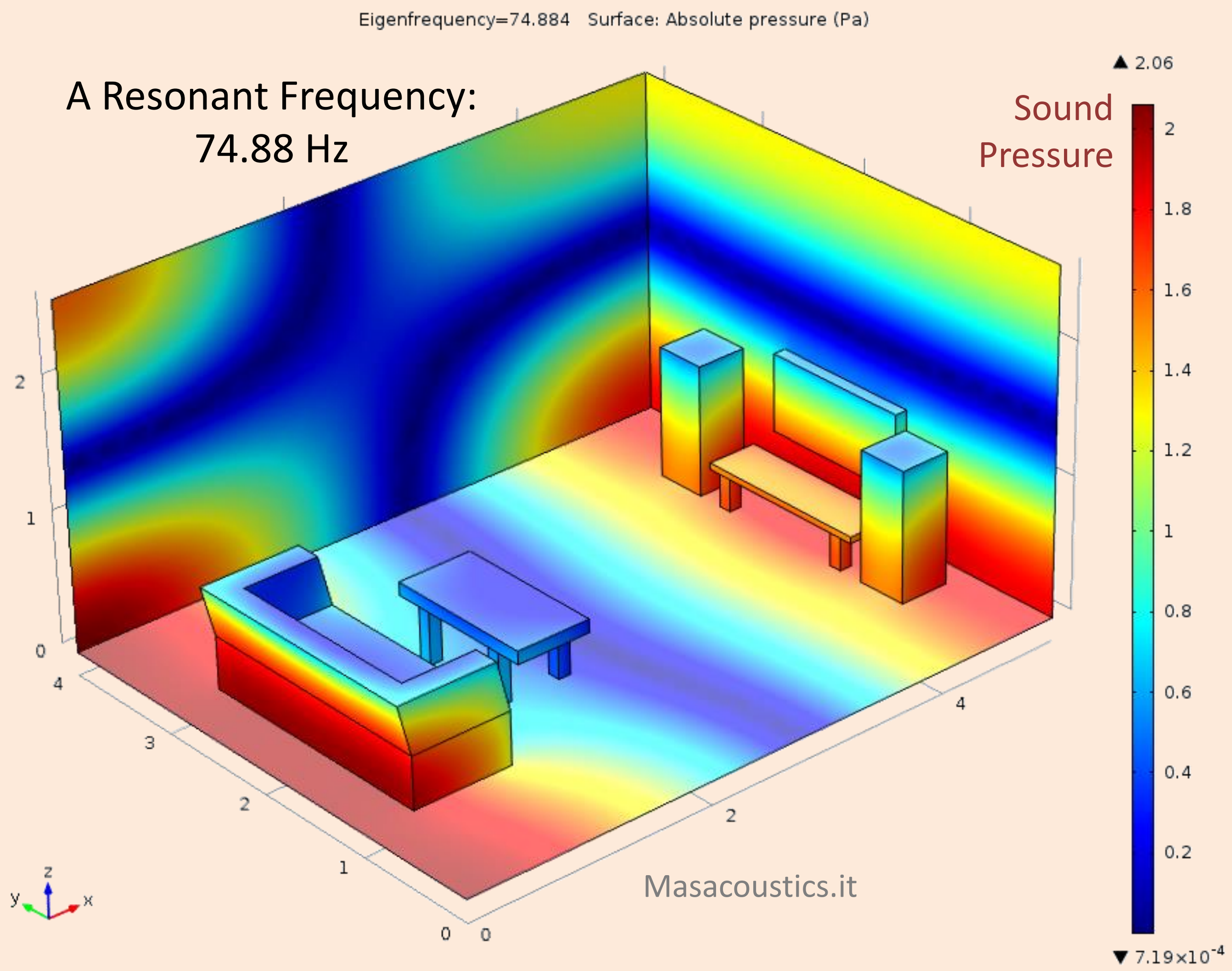
Measured Sound Spectrum of 12" Tom Drum

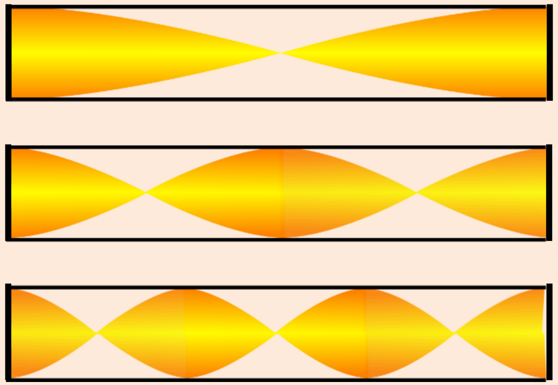


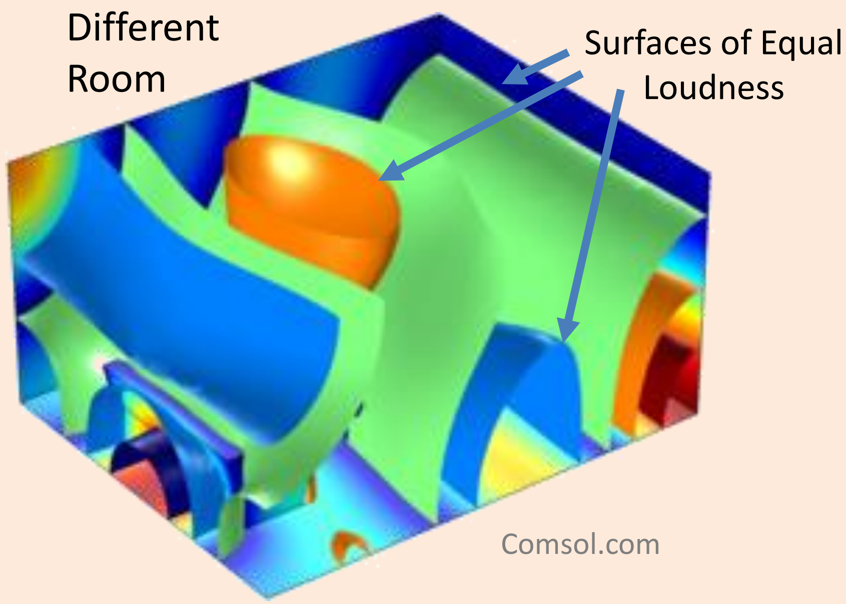
"Lug Tone"



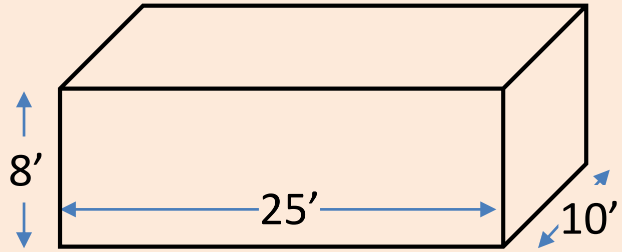
Room Modes

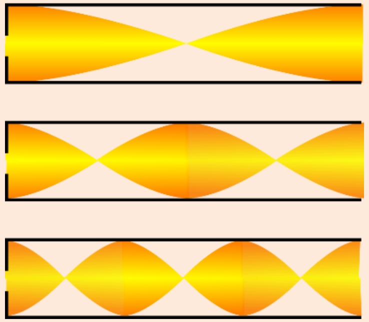

Eigenfrequency=74.884 Surface: Absolute pressure (Pa)
A Resonant Frequency:
74.88 Hz
Sound
Pressure
▲ 2.06
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
▼ 7.19×10^-4
Masacoustics.it



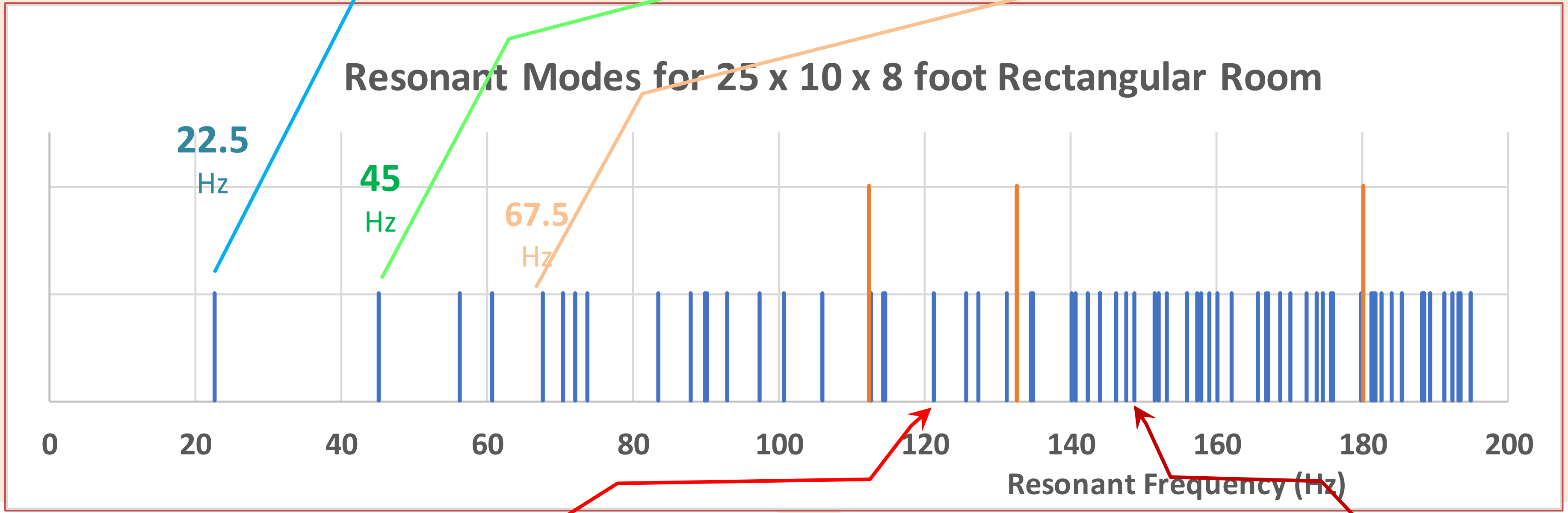

Different
Room
Surfaces of Equal
Loudness
Comsol.com

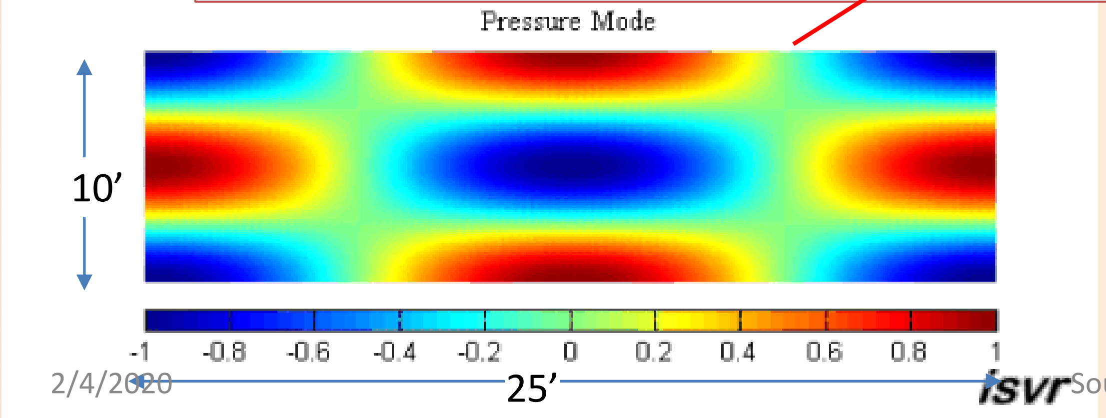
Room Modes

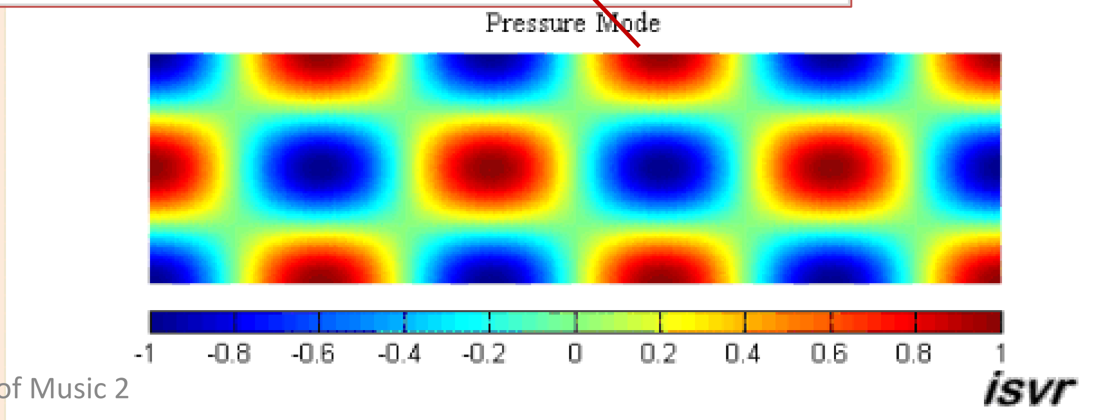




Longitudinal
“Organ Pipe”
modes







Course Outline

1. Building Blocks: Some basic concepts
2. Resonance: Building Musical 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