



# An Ear for Music



*Polyphonic Overtone Singing*  
Anna-Maria Hefe (2014)

## Session 7 Human Voice and Singing

OLLI at Illinois  
Spring 2024

D. H. Tracy



# Reconstruction of Sounds from Roman Cornu Horn



Floor mosaic, Zliten, Libya ca 1<sup>st</sup> Century CE. Musicians at Gladiatorial Contest with Roman Tuba, Hydraulis pipe organ, two Cornua.

Music played on Virtual Cornu using Modalys simulation program.

[René Caussé & team, Institute for Research and Coordination in Acoustics and Music, Paris (2017)]

Cornu dimensions, materials and construction details from Pompei artifacts at Museo Archeologico Nazionale di Napoli.  
3.4 m Length, Conical, Sheet metal, Bronze Alloy





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# Course Outline



1. Building Blocks: Some basic concepts
2. Resonance: Building Complex Sounds
3. Hearing and the Ear
4. Musical Scales
5. Musical Notation; String Instruments
6. Pipe Instruments and Timbre
- 7. Human Voice and Singing**
8. Harmony and Dissonance; Chords

# Singing



# Coloratura Soprano Audrey Luna

Audrey Luna (2010)  
singing *Mad Scene* from  
Donizetti's  
*Lucia di Lammermoor* (1835)

Listen carefully  
to the lyrics....



# Coloratura Audrey Luna

Audrey Luna (Nov. 2017)  
hits A6 at the Met  
in Thomas Adès's  
*The Exterminating Angel*

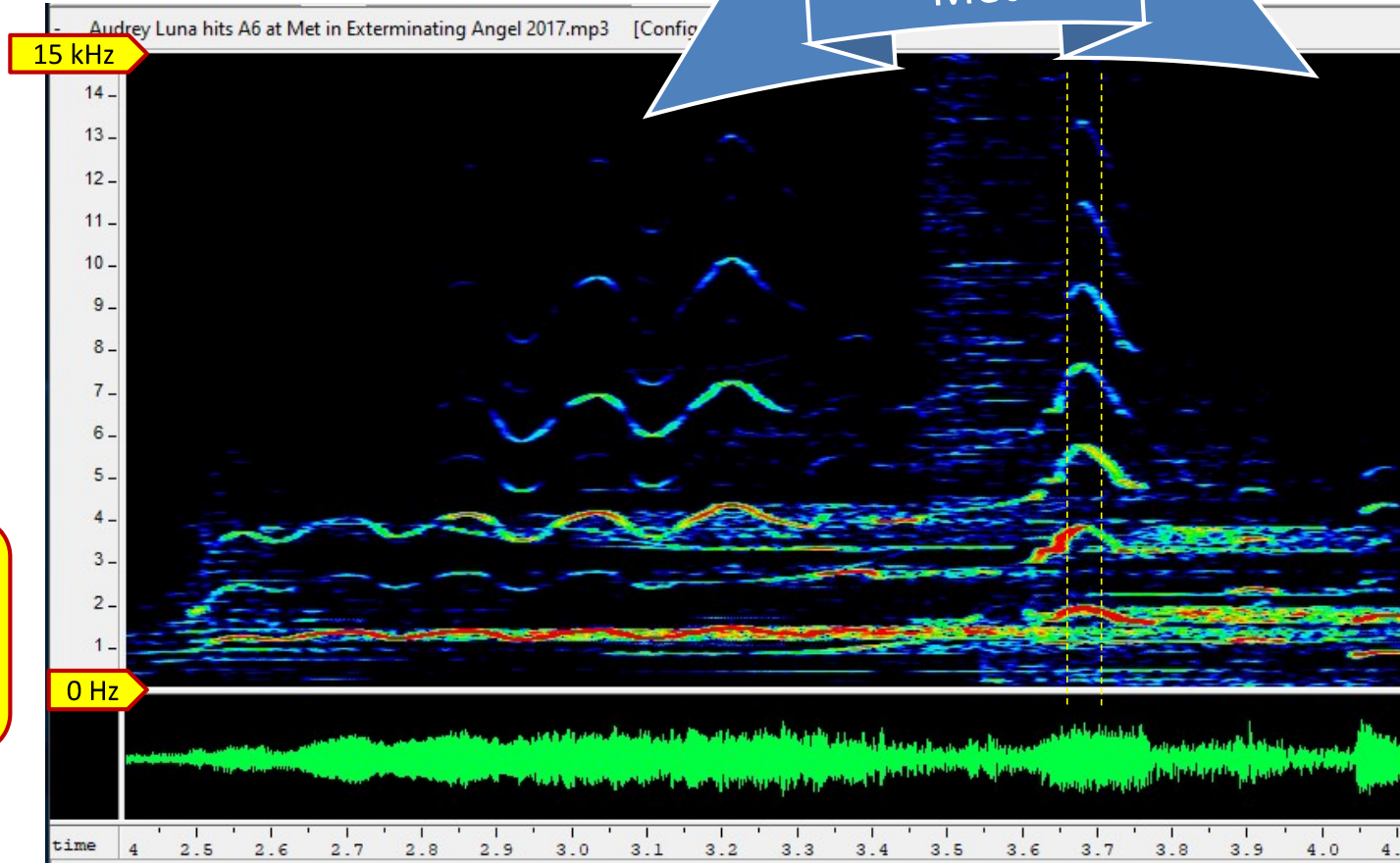
She actually hit above  
A#6  
(1910 Hz)



# Coloratura Audrey Luna

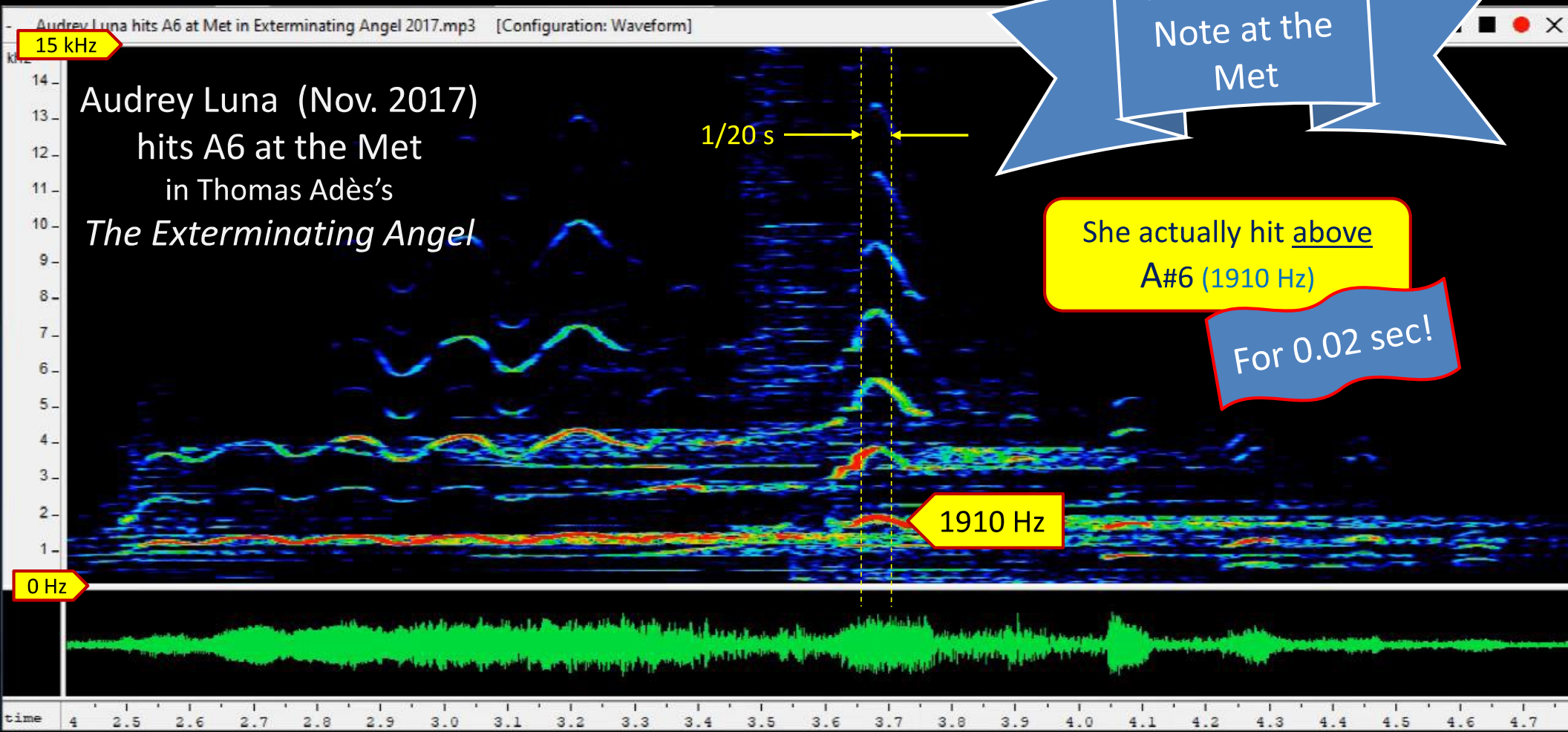
Audrey Luna (Nov. 2017)  
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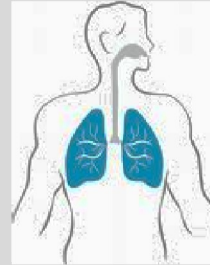
# Coloratura Audrey Luna



# The Singing Voice as a Musical Instrument

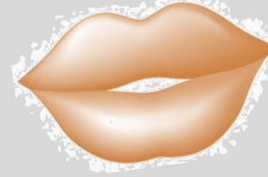


Source of  
**Air Pressure**



+

Controllable  
Vibrating  
**Valve**



Lips

+

Variable  
Acoustic  
**Resonator**



$f_1$  + Harmonics

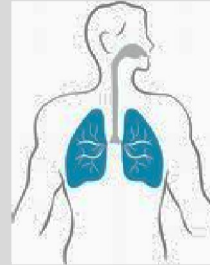
Selects desired harmonics



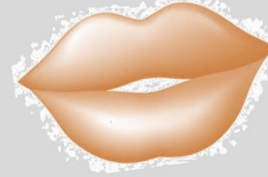
# The Singing Voice as a Musical Instrument



Source of  
**Air Pressure**



+  
Controllable  
Vibrating  
**Valve**



Lips

+

Variable  
Acoustic  
**Resonator**

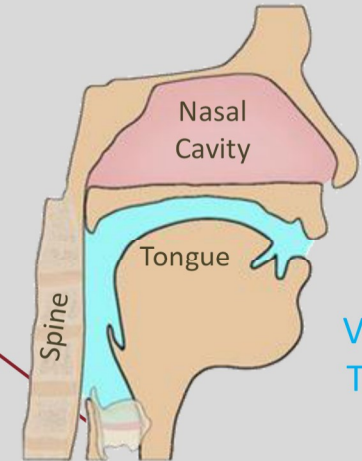


$f_1$  + Harmonics

Selects desired harmonics



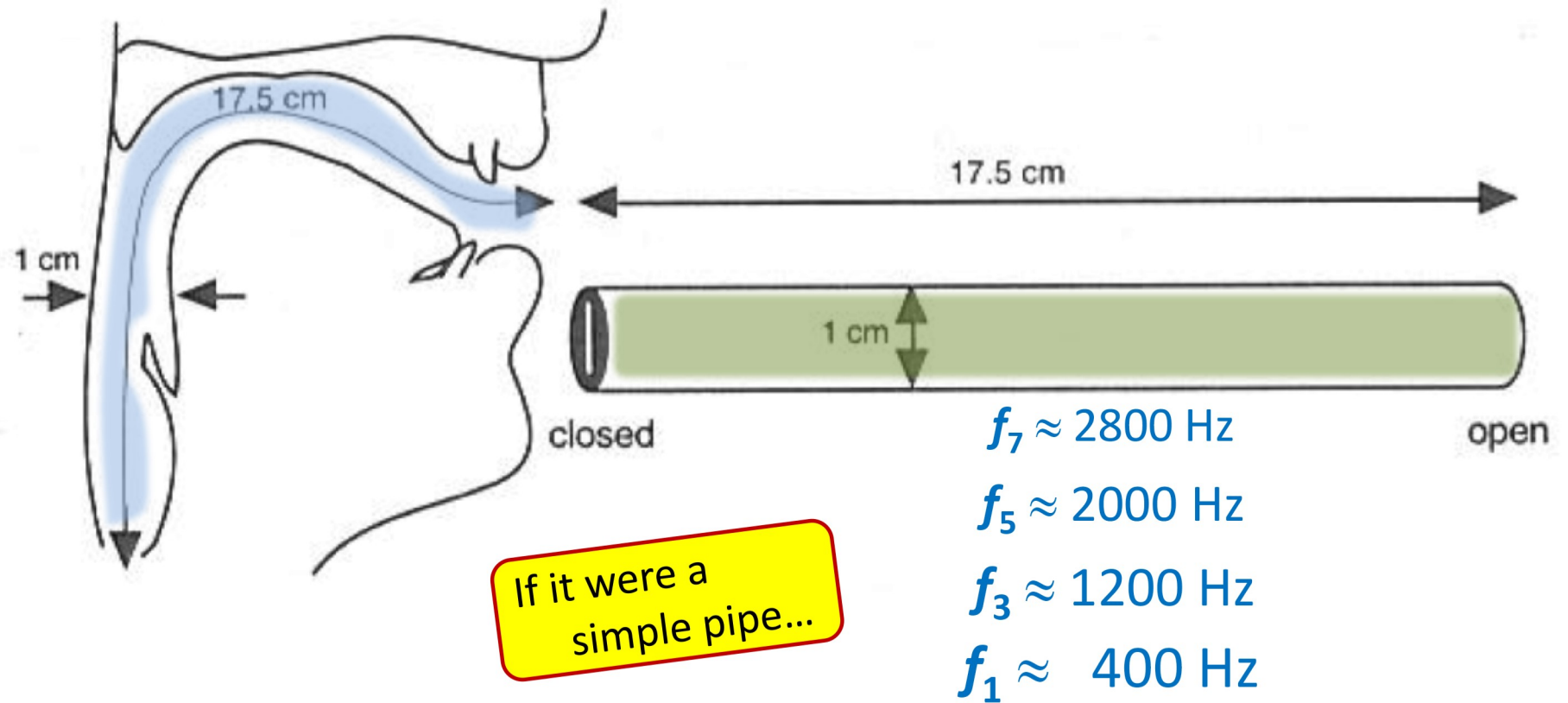
Vocal  
Folds



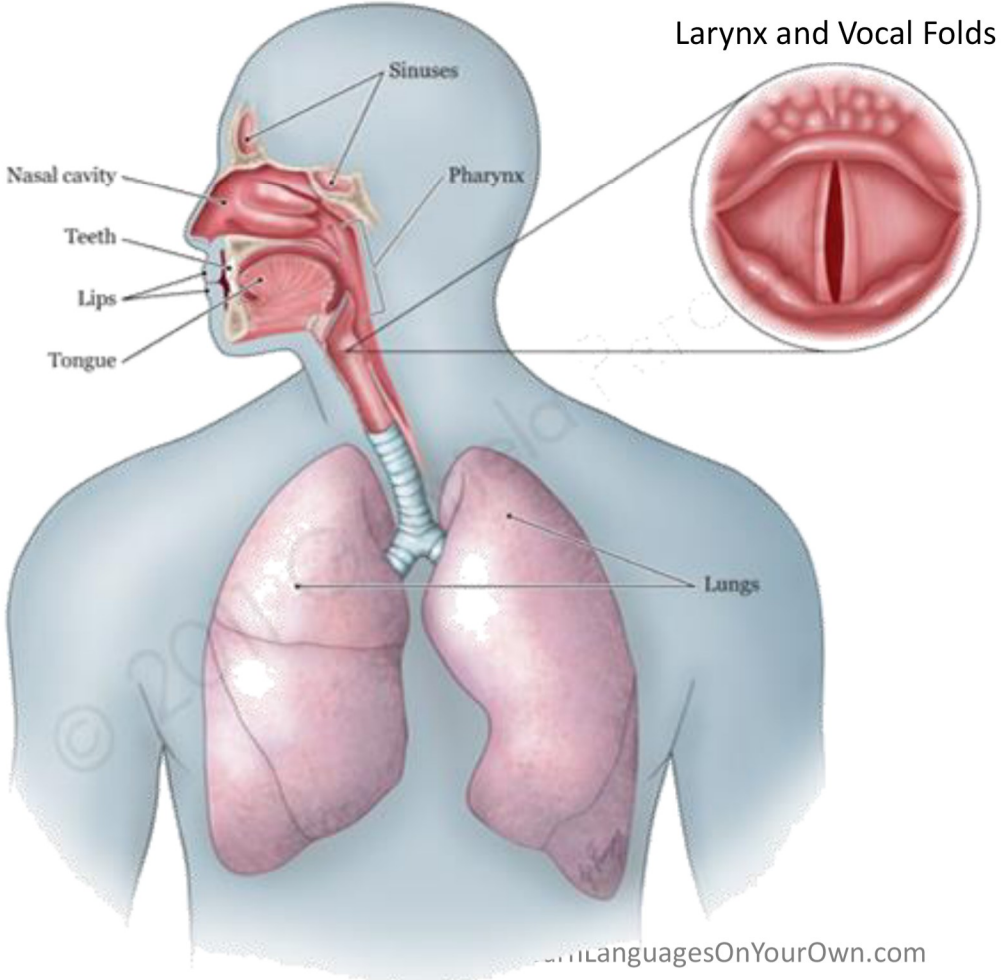
Vocal  
Tract



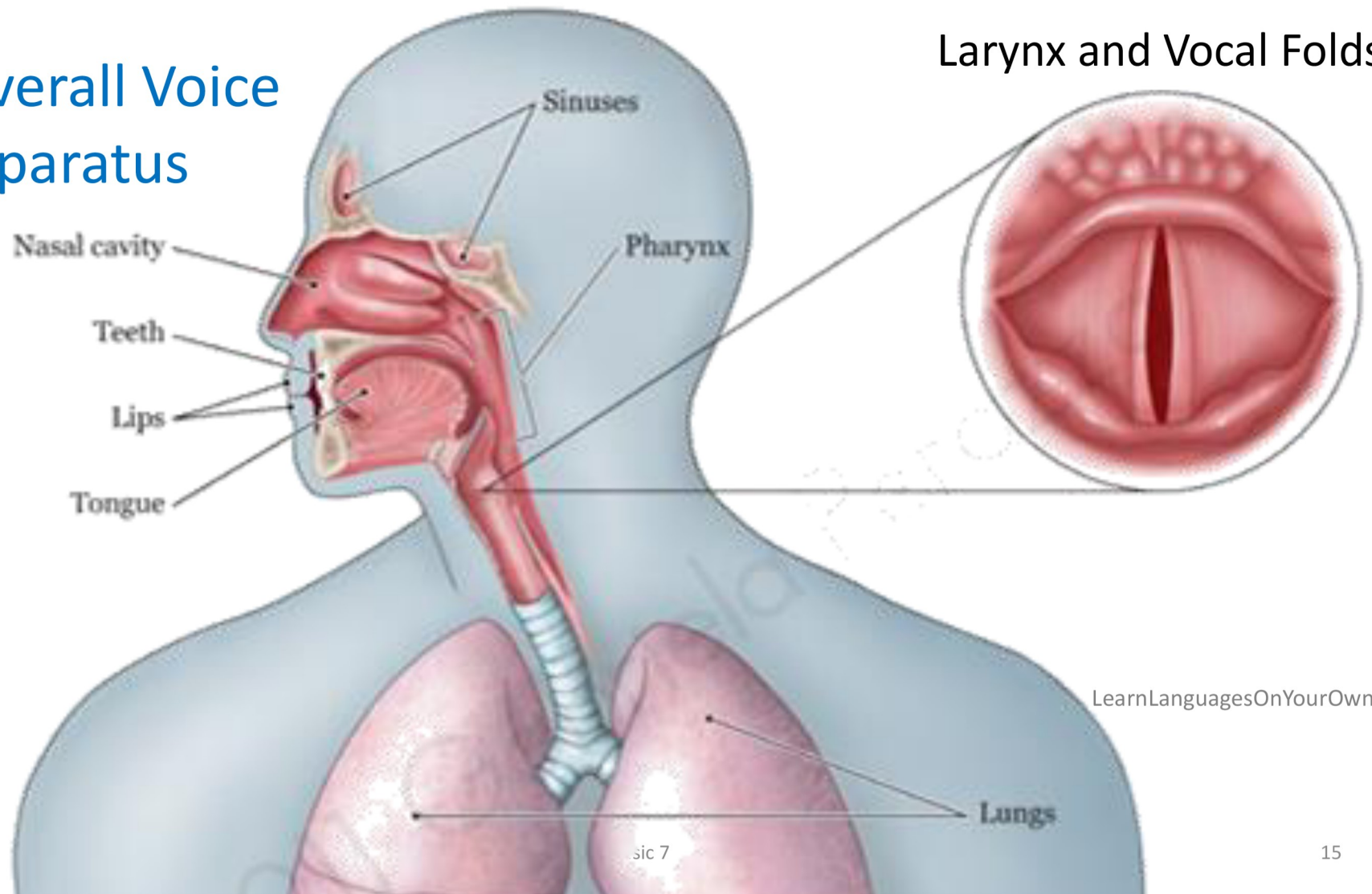
# Vocal Tract Crudely Similar to Closed/Open Pipe



# The Overall Voice Apparatus



# The Overall Voice Apparatus



## Larynx and Vocal Folds

LearnLanguagesOnYourOwn.com





# But Not All Sounds are Voiced using Vocal Folds

## Also:

- Sounds produced by turbulent flow
  - sss, shh, fff, th
  - *Fricative*
- Sounds produced by sudden release of pressure
  - t, k, p
  - *Plosive*
- Combinations of these with Voicing
  - z, v, b, d, g

These are not very musical  
—  
De-emphasized in Singing

also:

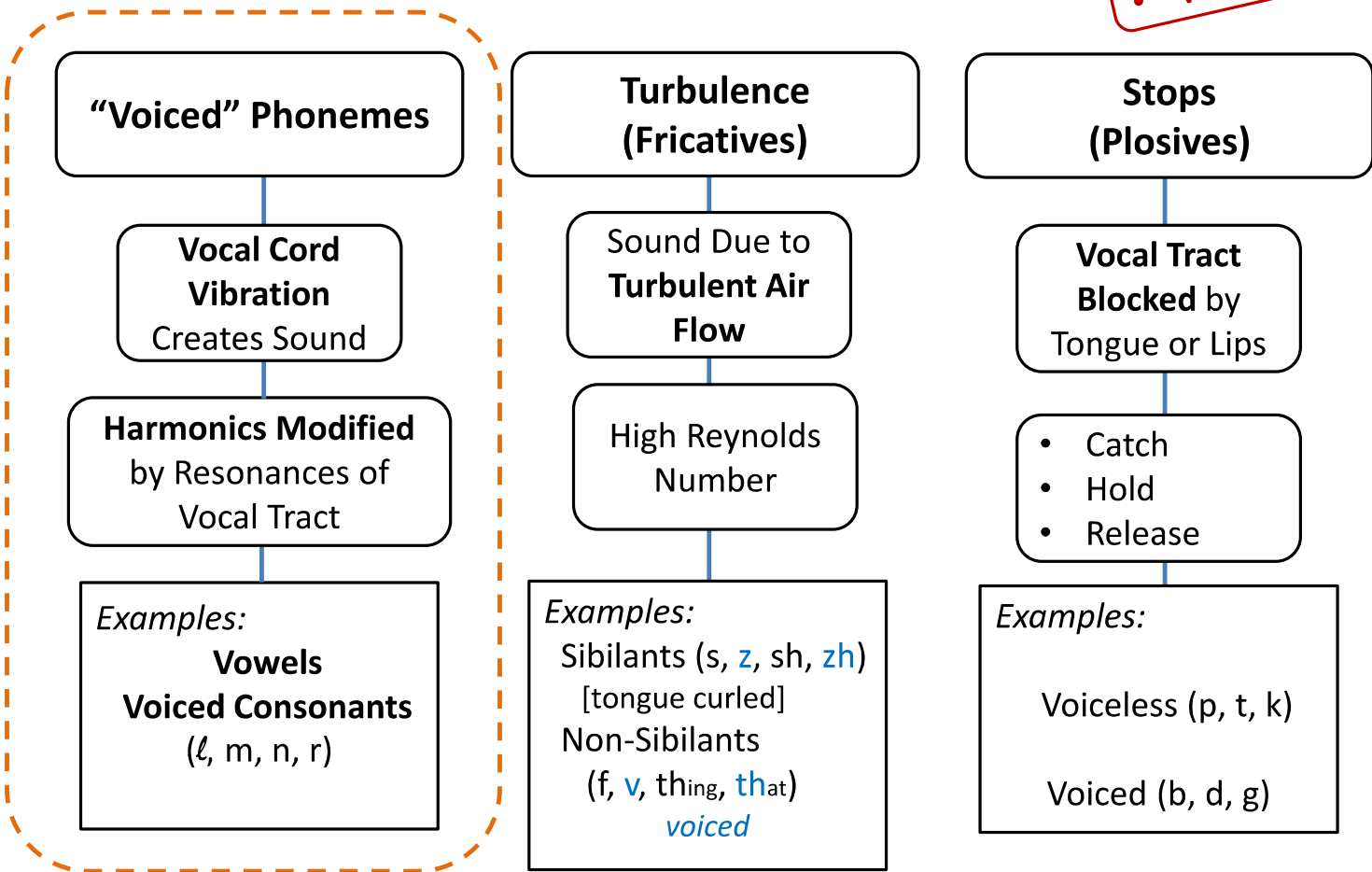
- Clicks
- Whistles



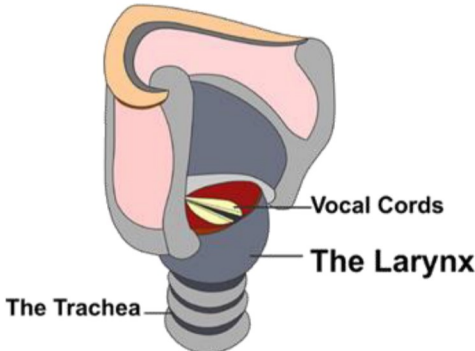
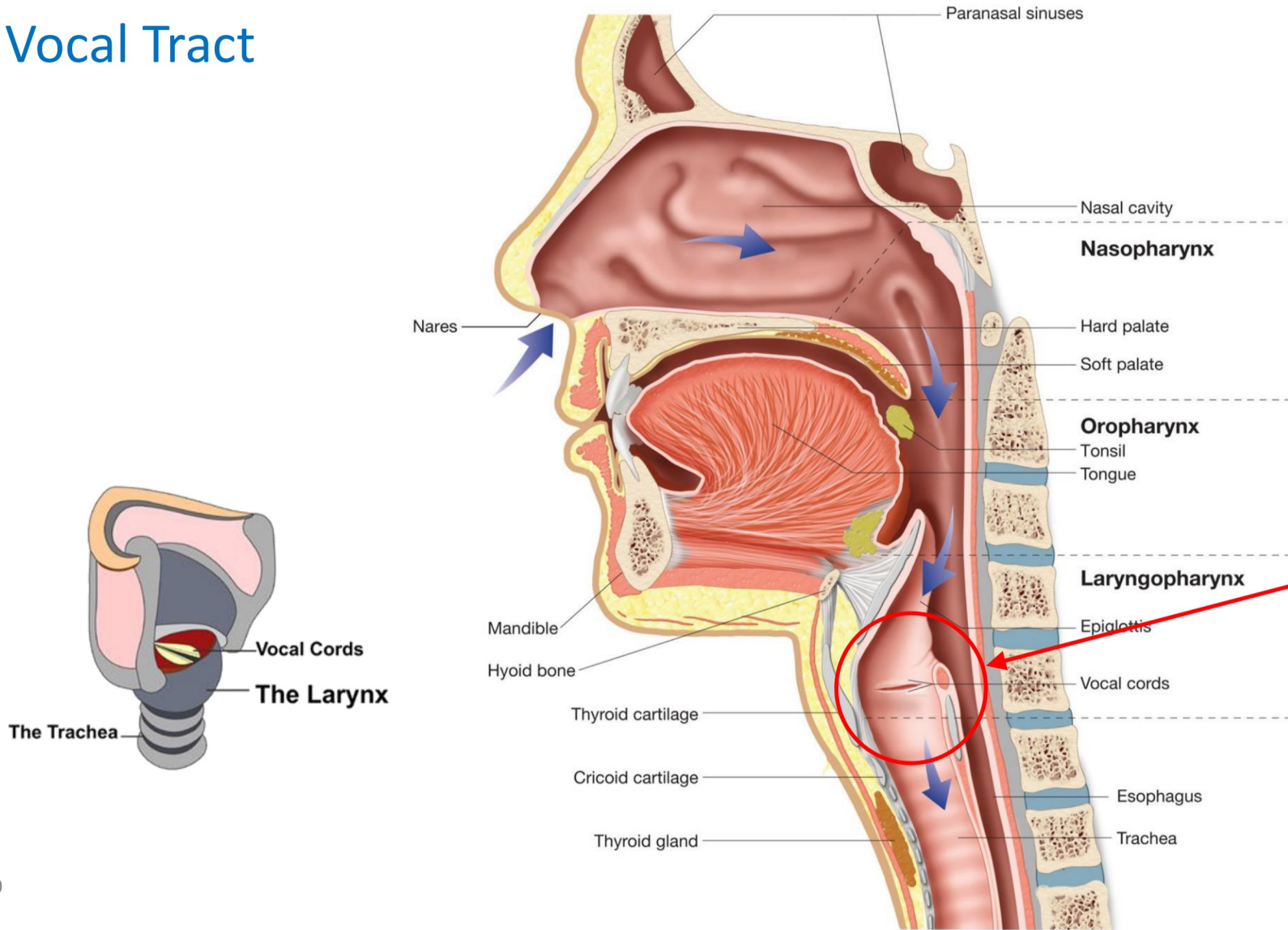
# Types of Vocalization

- Clicks
- Whistles

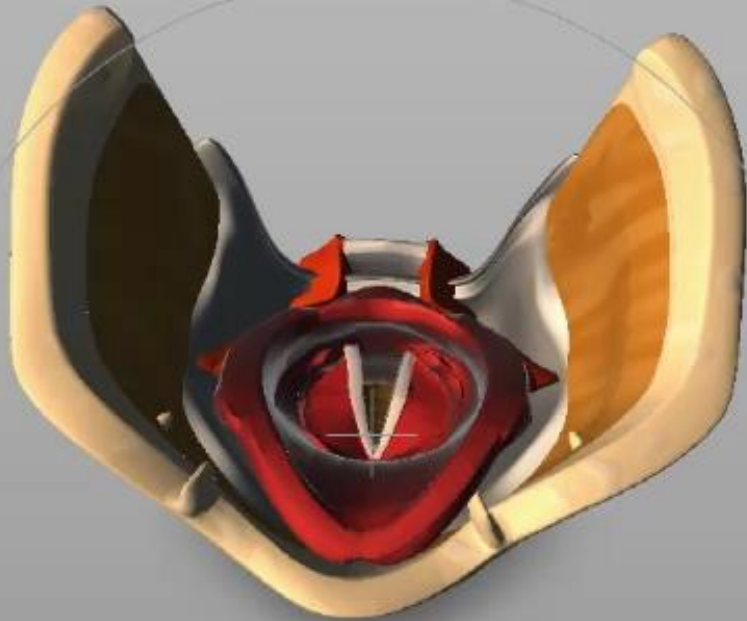
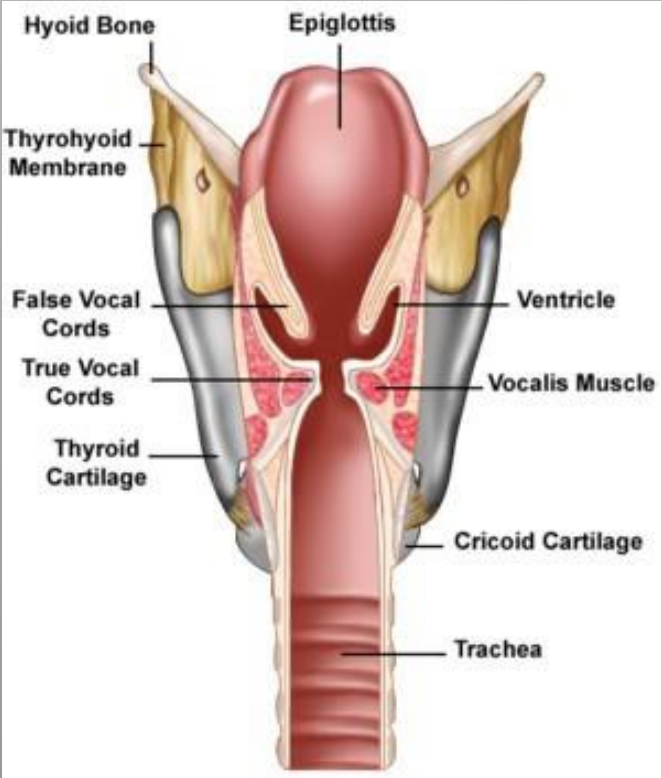
Biggies for Singing



# Vocal Tract



# Larynx 3D Model



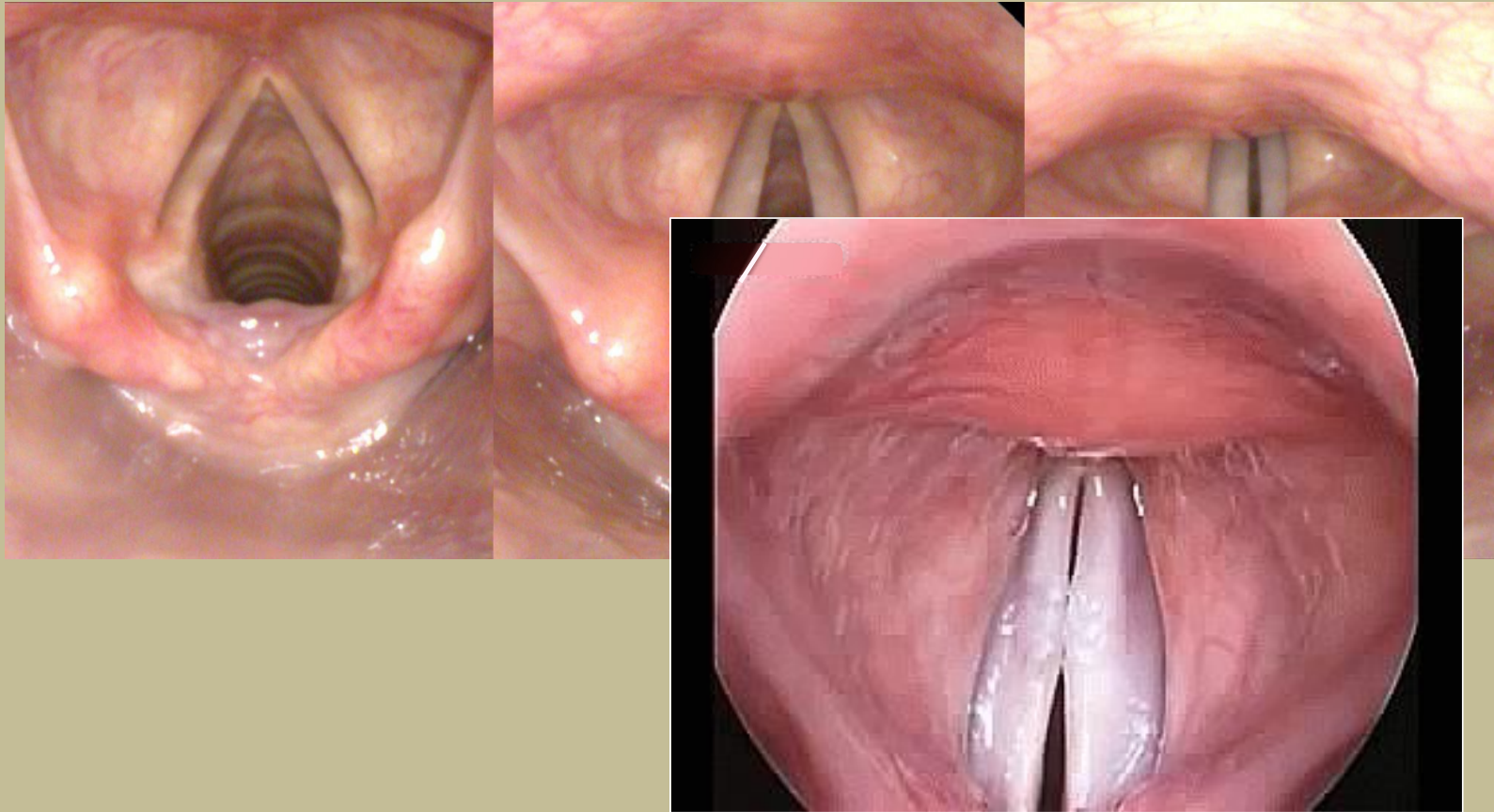
Top View





# Vocal Folds (Cords): Top View

Open vs Closed



# Phonation:

## Generating Chopped Glottal Air Flow via Vocal Fold Vibrations

### Phonation Types:

#### 1. "Breathy"

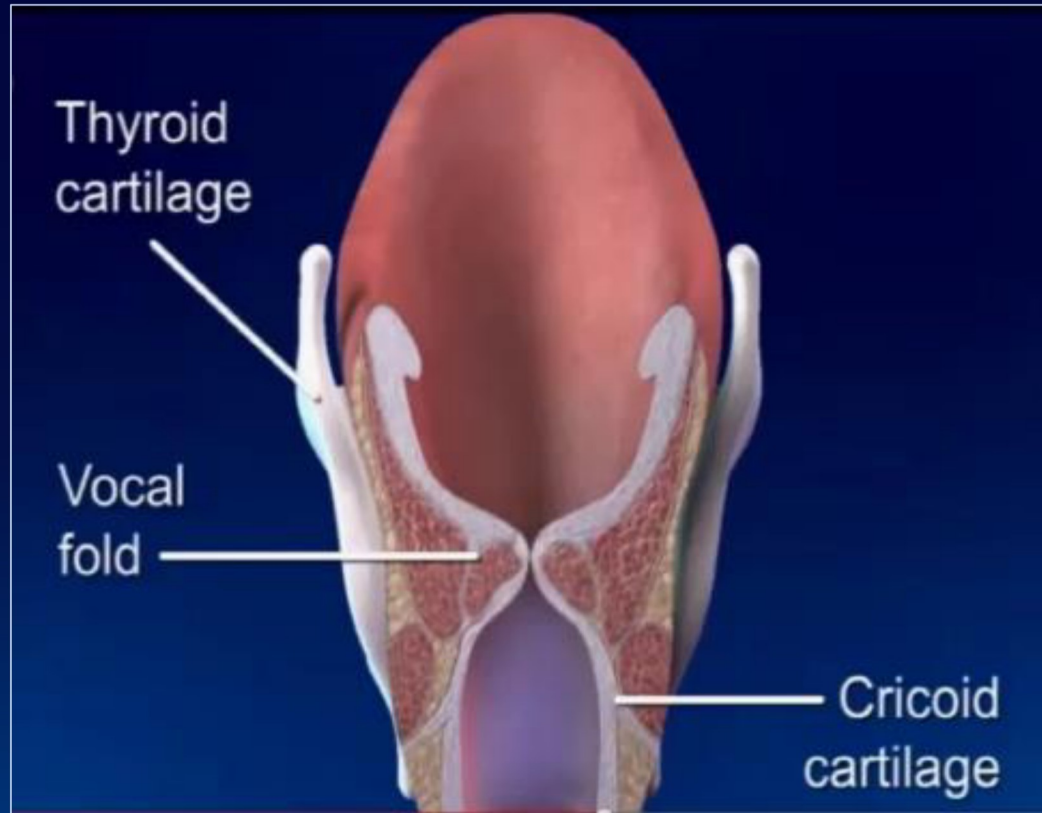
Folds do not close  
Weak harmonics



#### 2. Modal (flow, normal)

#### 3. "Pressed"

Folds tightly squeezed  
Shrill sound



Power to Sing



Duck Call Demo

# Phonation: What if we Eliminated the Vocal Tract?

## Estimated Vocalization without Modification by Vocal Tract

1. **Synthetic voice** (glissando)



2. **Male speech voice**  
(based on EGG)



3. **Singing (Modal Phonation)**

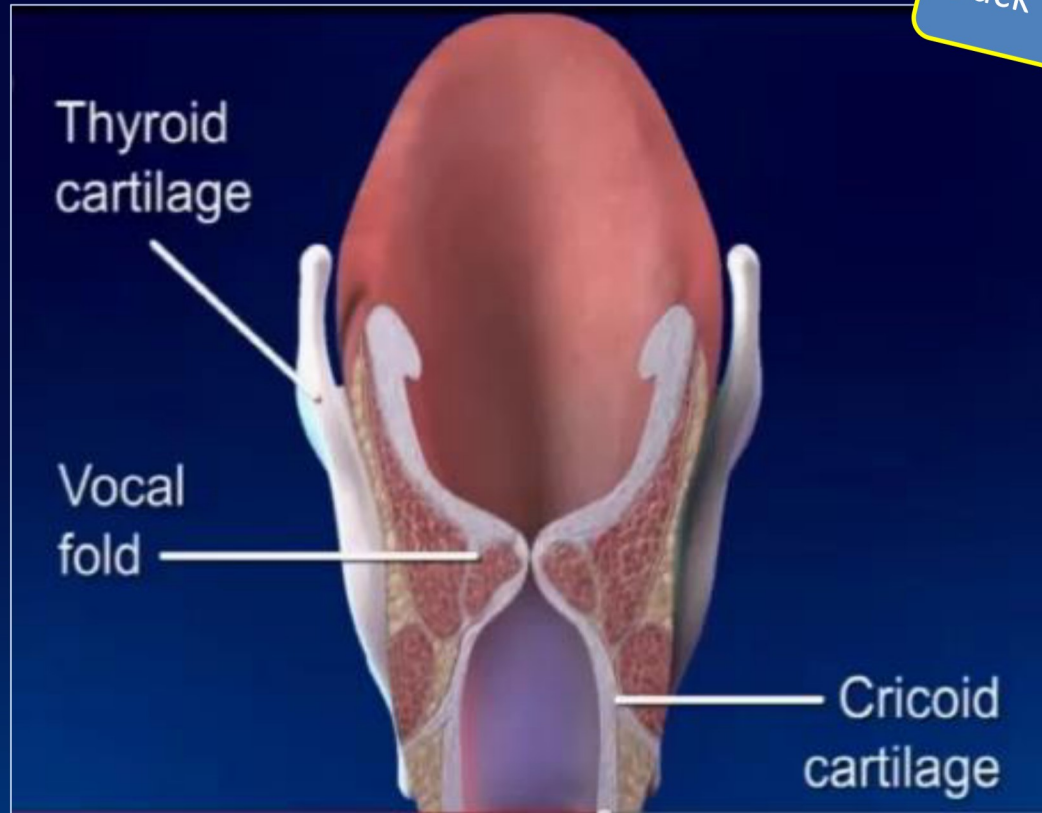
100 Hz



260 Hz



750 Hz

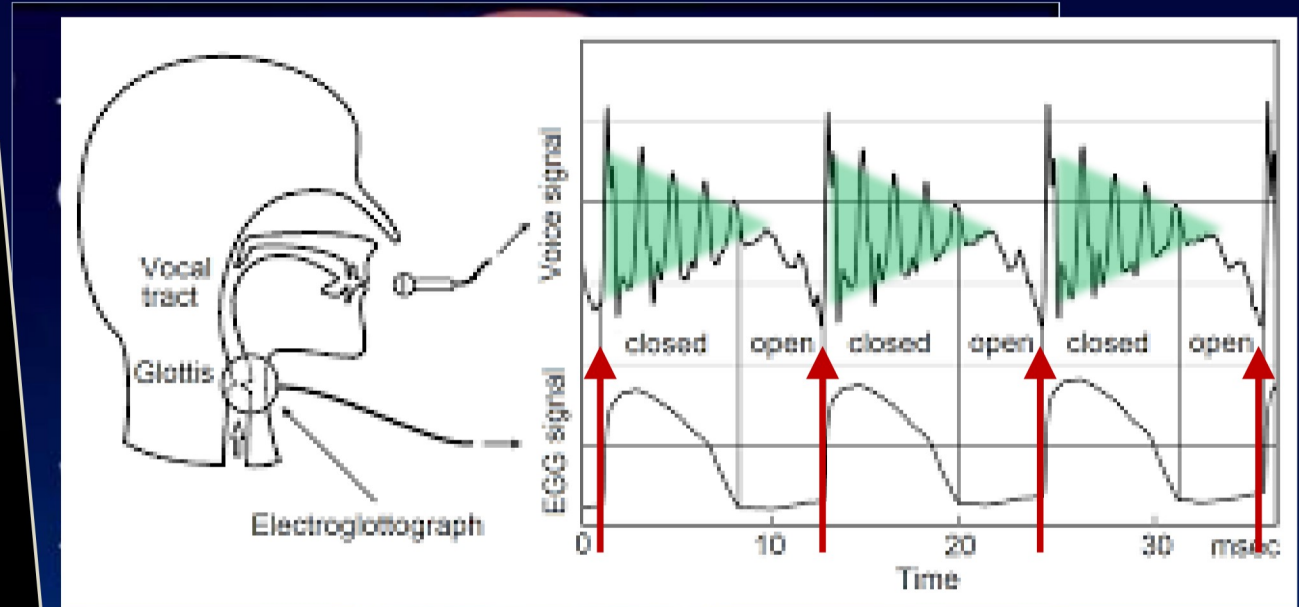
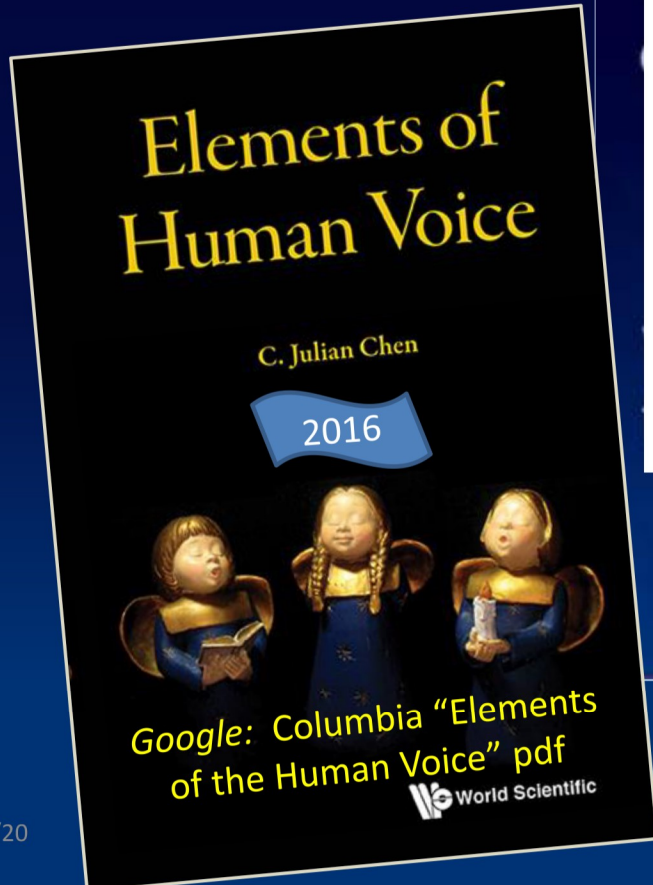


Power to Sing



# Glottal Closings Generate Most Sound

Vibration of  
Vocal Fold



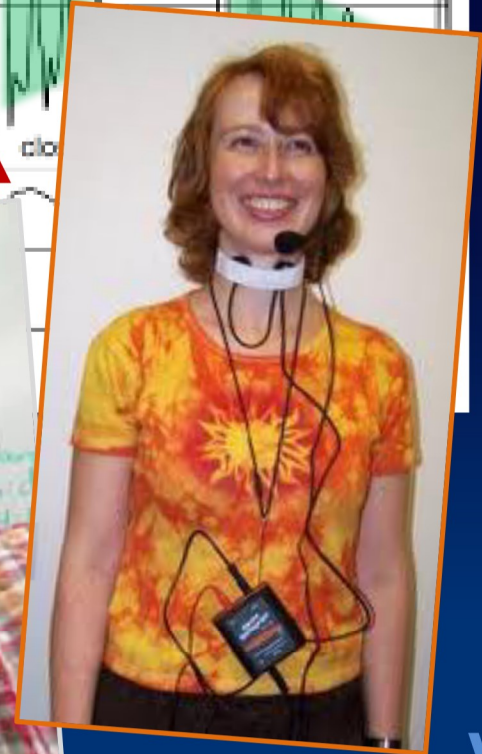
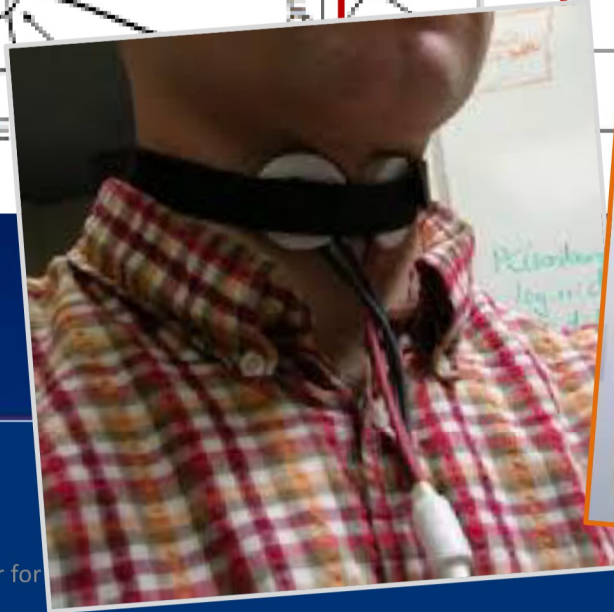
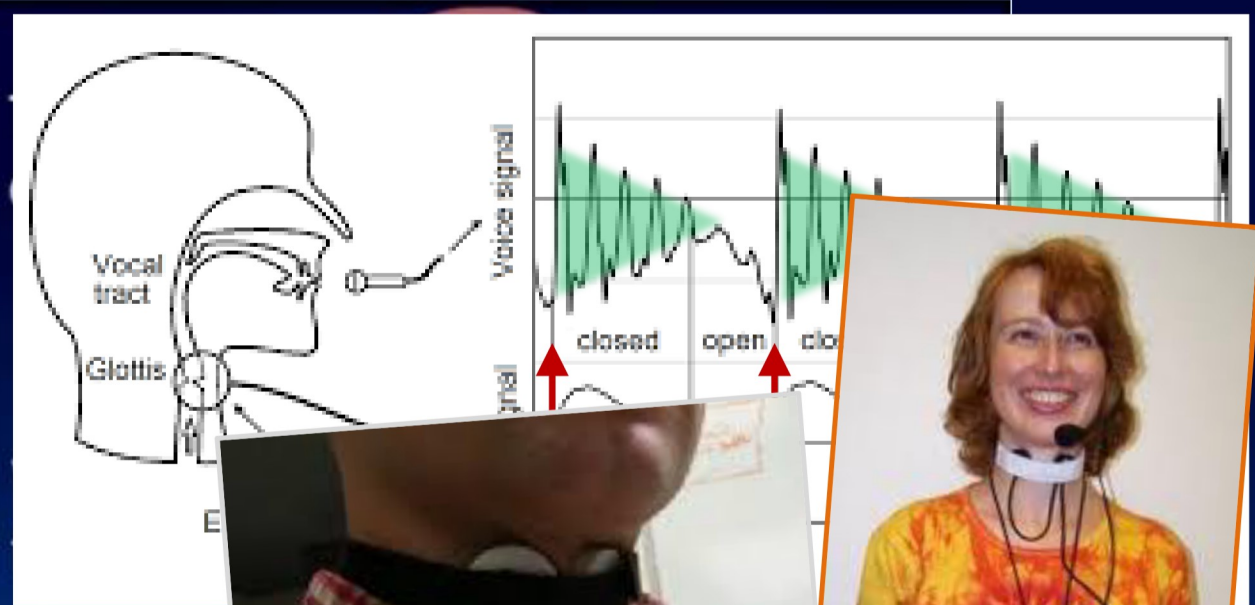
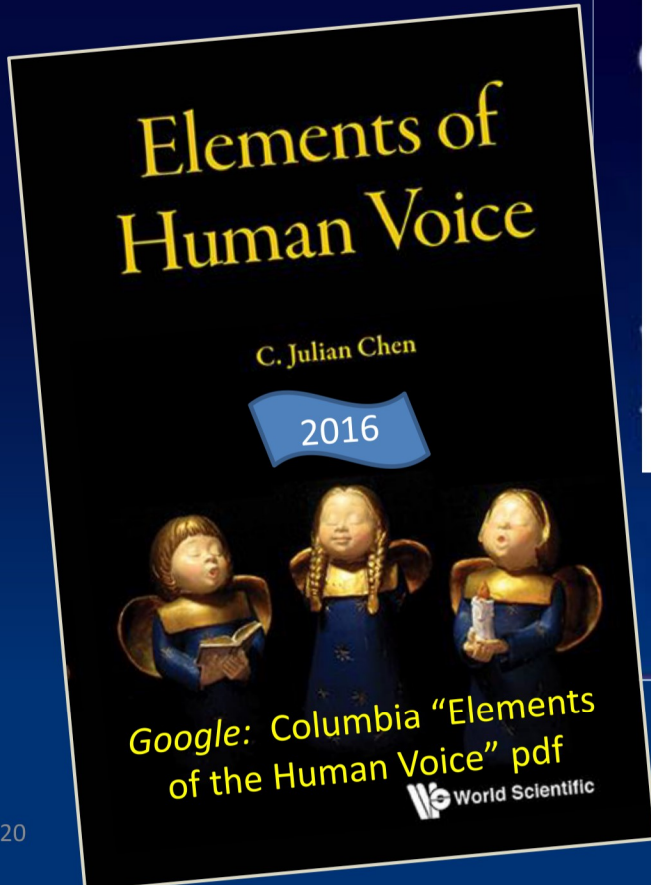
Power to Sing



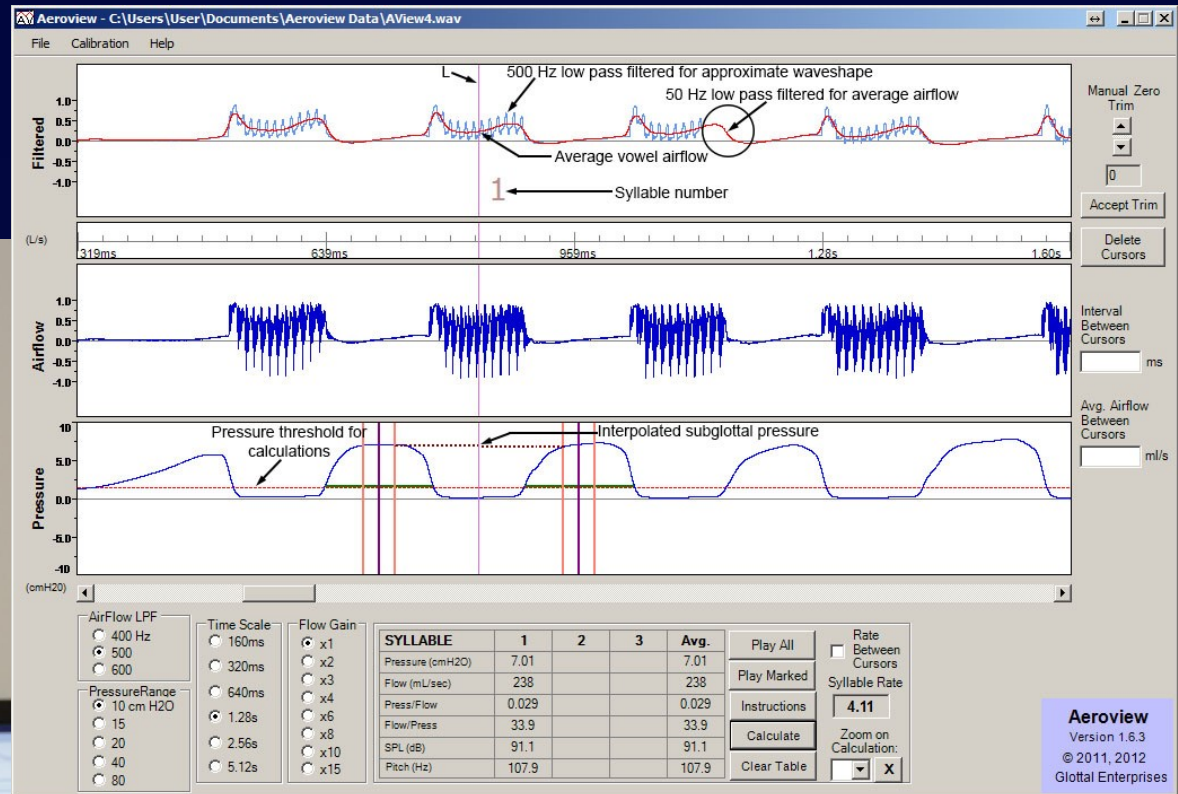
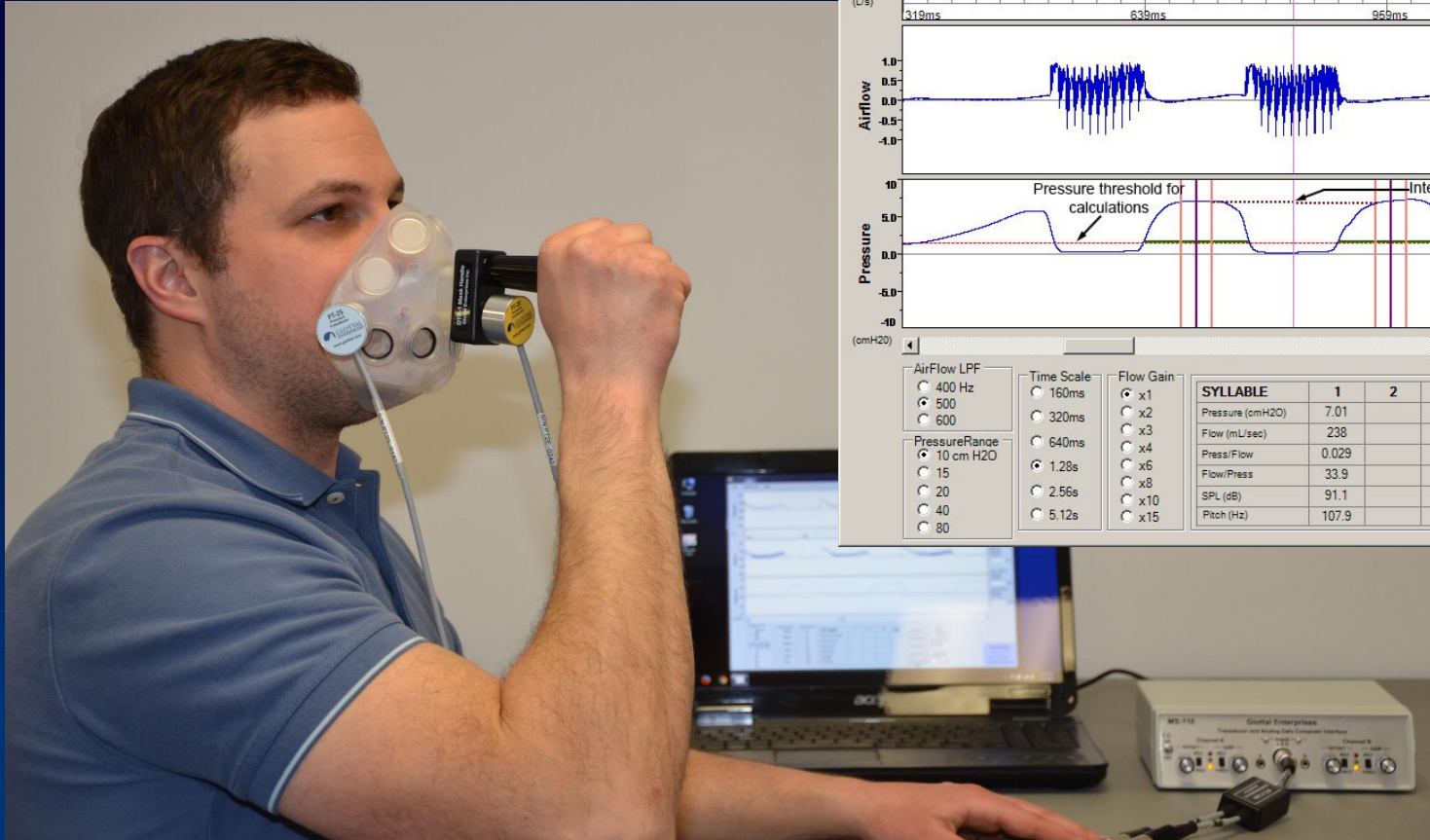


# Glottal Closings Generate Most Sound

## Vibration of Vocal Fold



# Glottal Airflow Mask System



# Electroglottograph



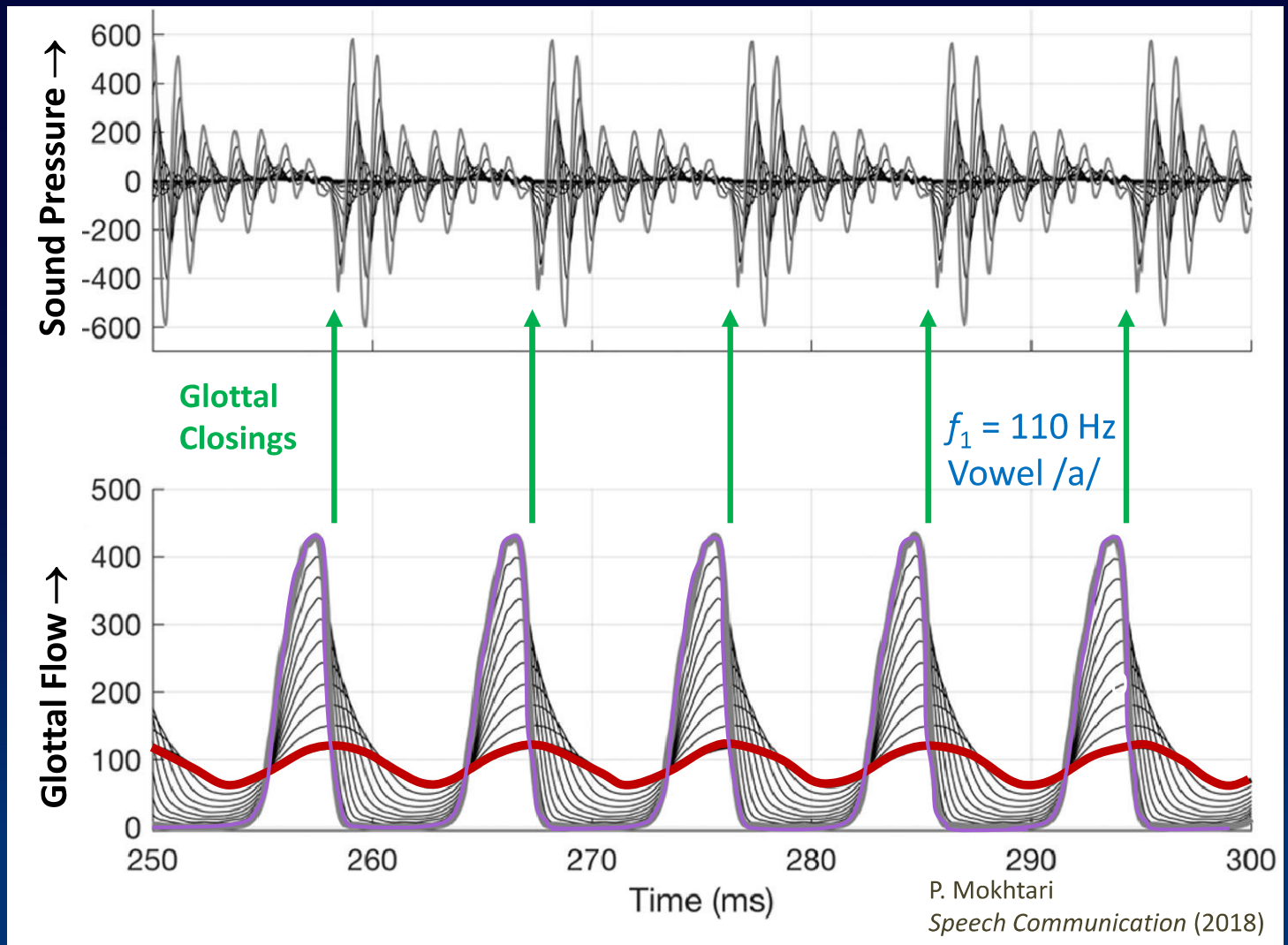


# Phonation:

## Glottal Flow and Resulting Sound

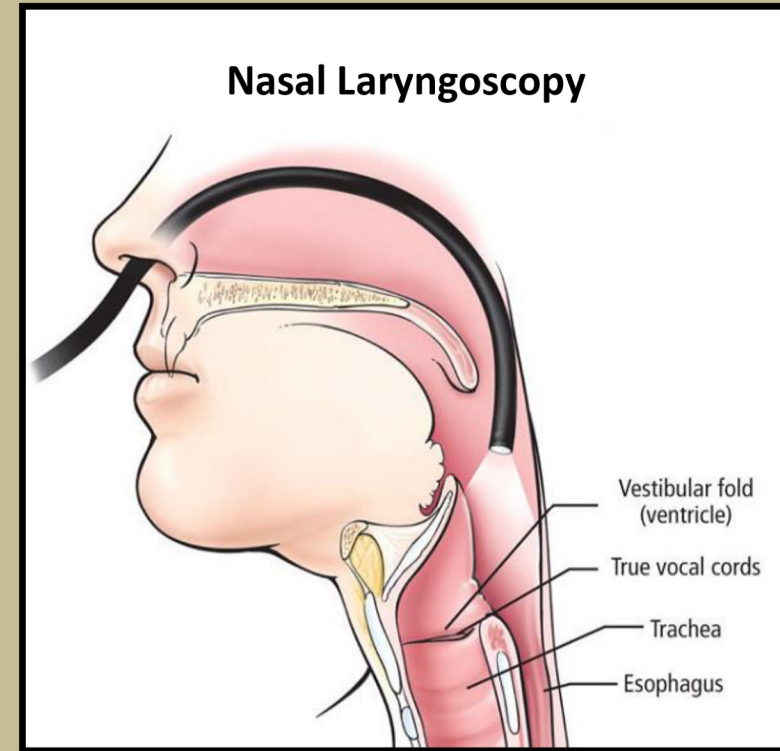
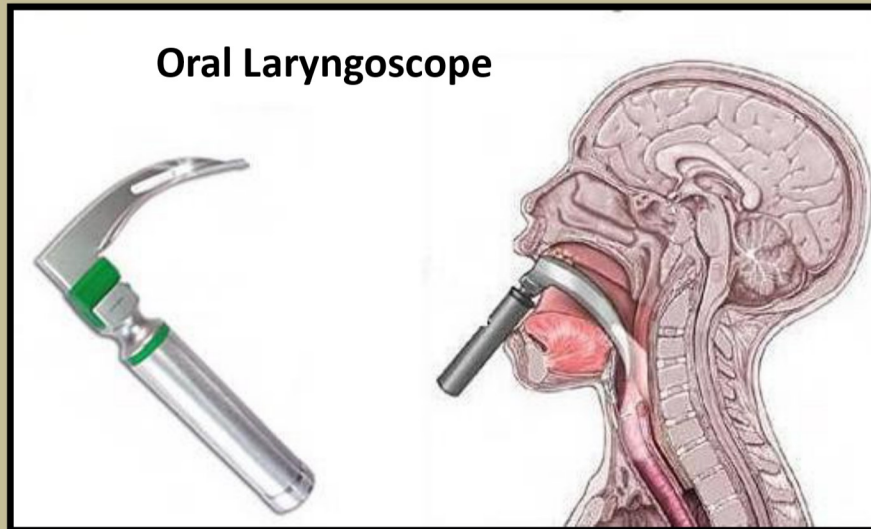
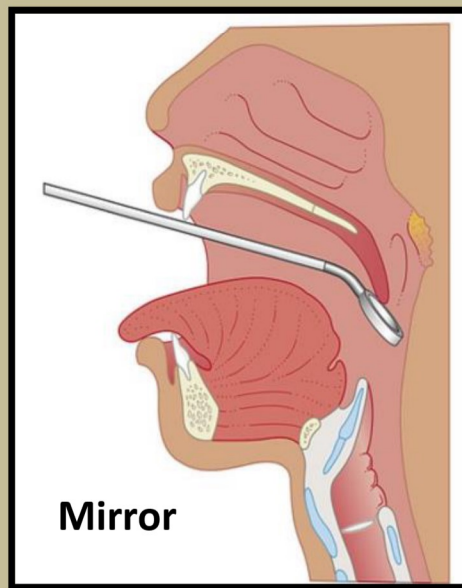
Pressed Phonation

Breathy Phonation





# Laryngoscopy: Viewing the Vocal Folds

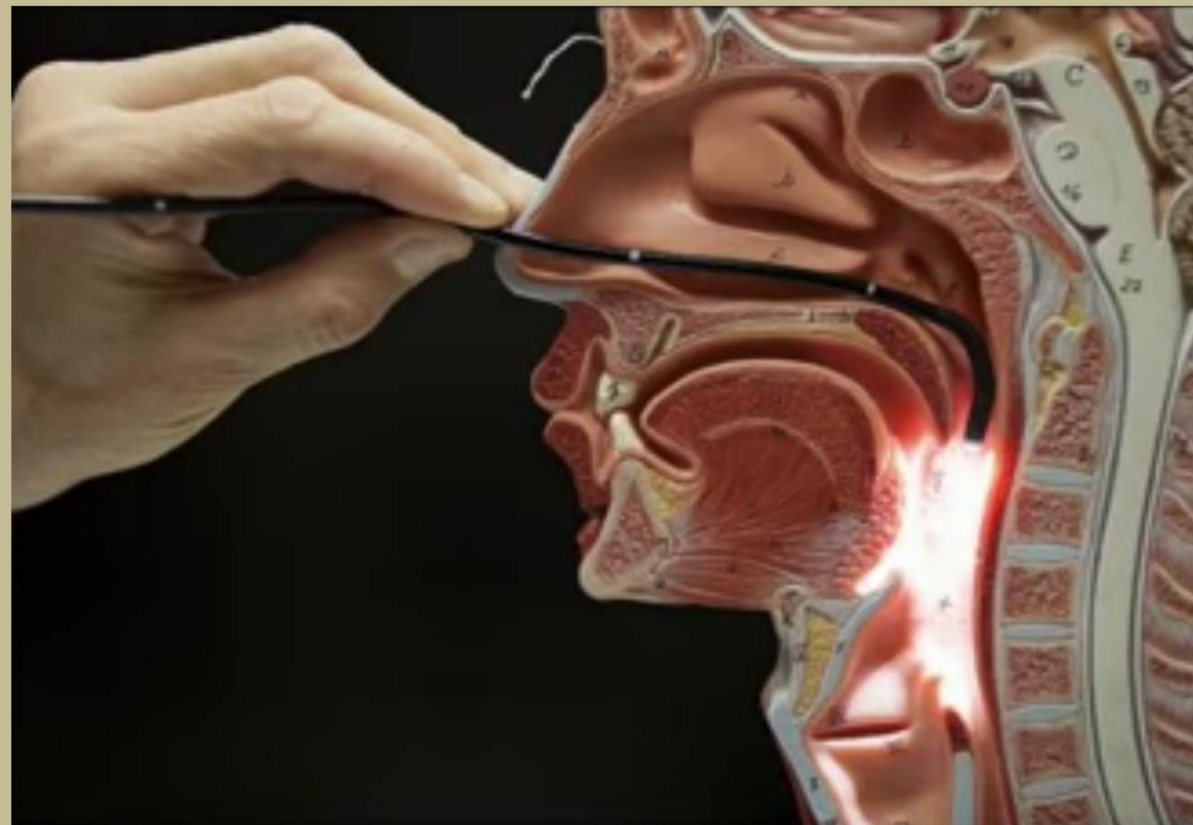


# Laryngoscopy: Viewing the Vocal Folds

Using a Stroboscopic Lamp  
flashing at the vibration rate of  
the vocal folds freezes the action



4/12/20



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29



Movie



Power to Sing

7/14/20

AN ENT FOR MUSIC 7



# Action of Vocal Folds While Singing

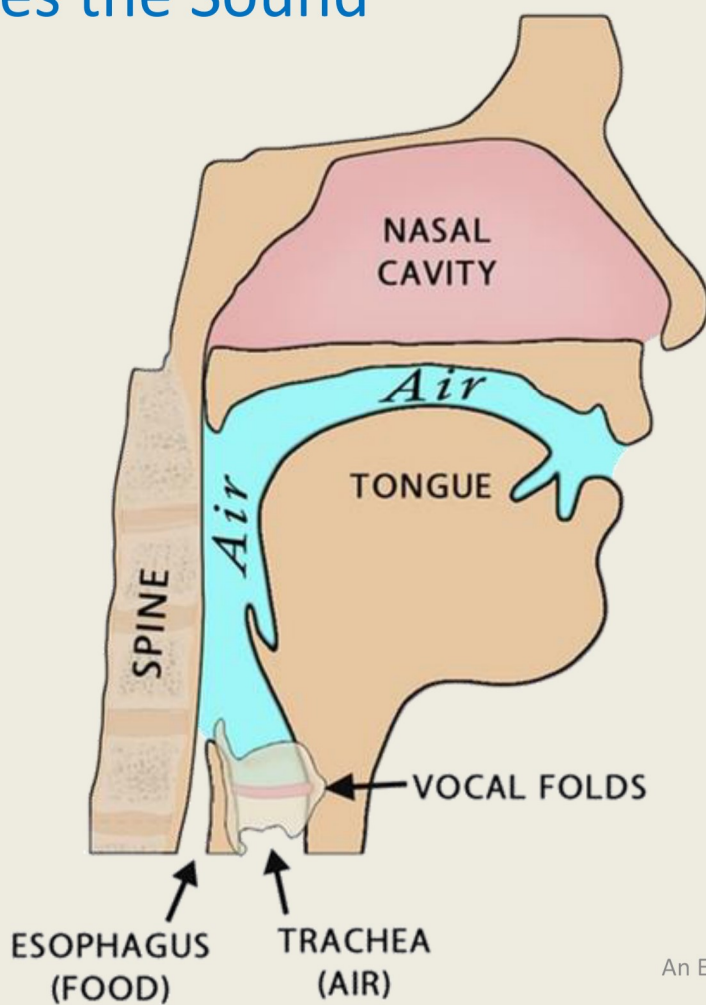


Movie

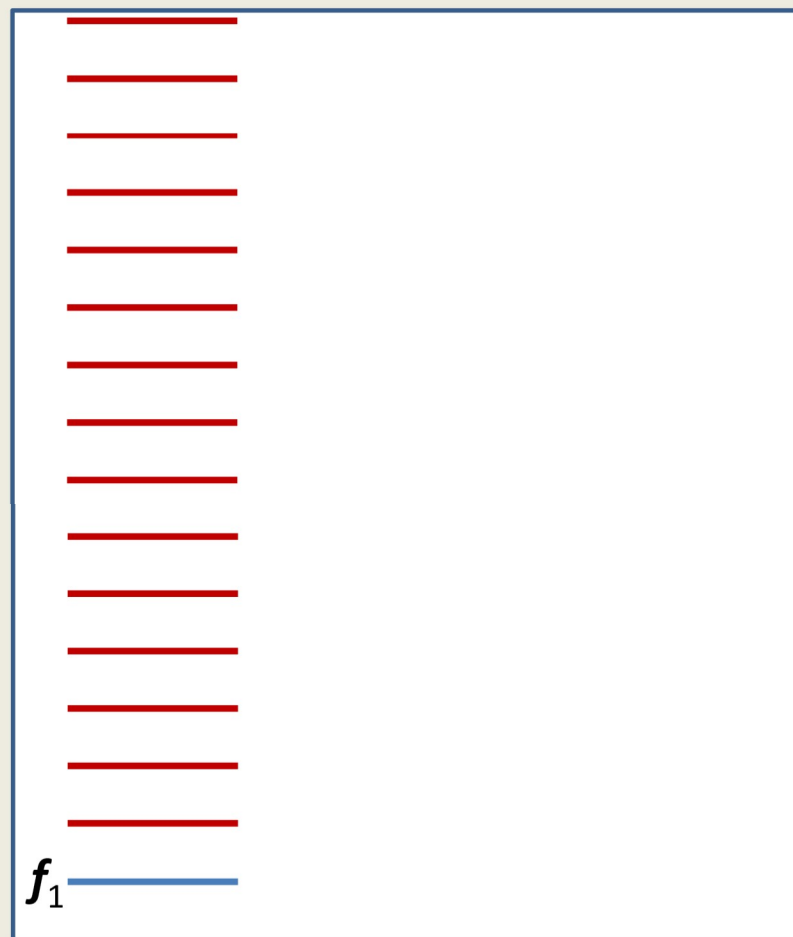




# The Vocal Tract Modifies the Sound



Frequency →



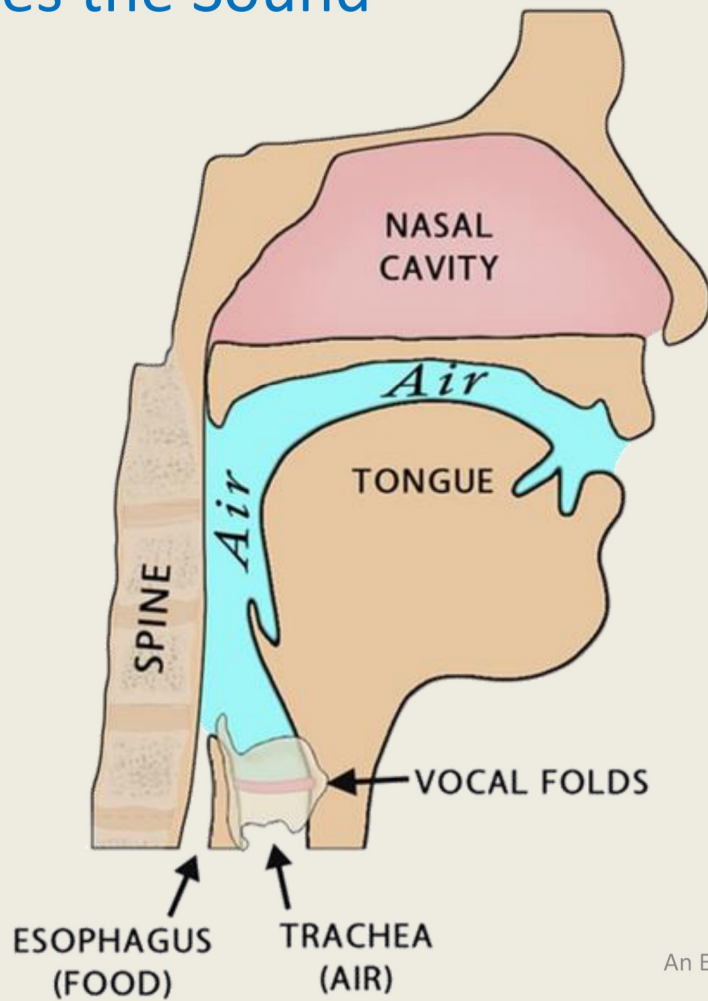
Vocal  
Folds

Vocal Tract  
Resonances  
**(Formants)**

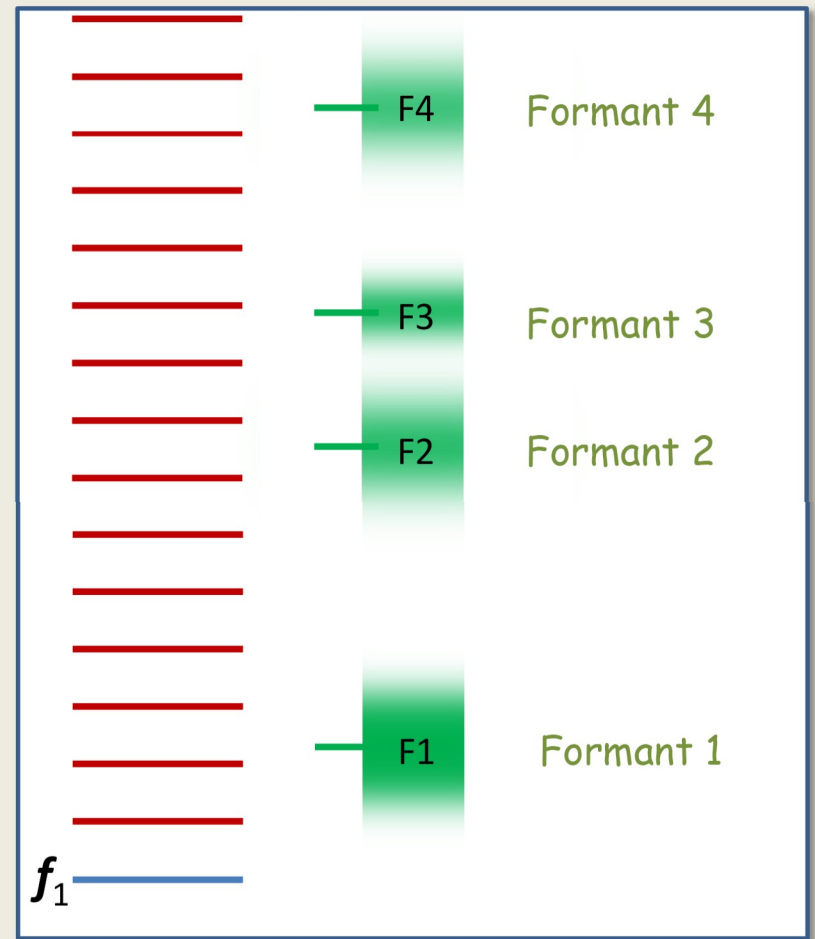
Result



# The Vocal Tract Modifies the Sound



Frequency ↑

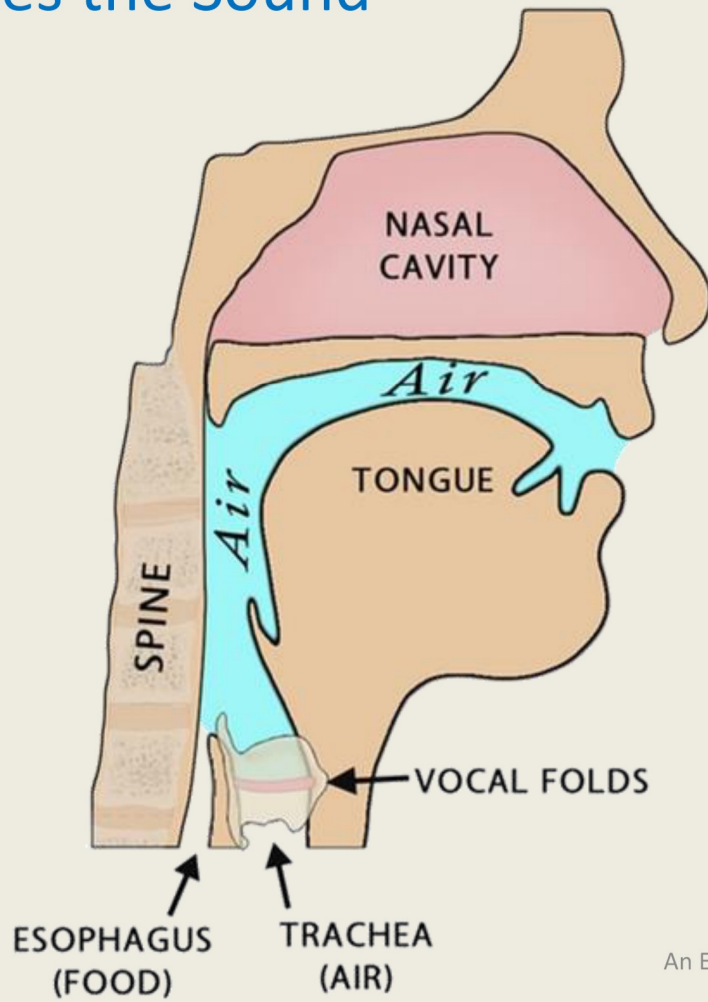


Vocal  
Folds

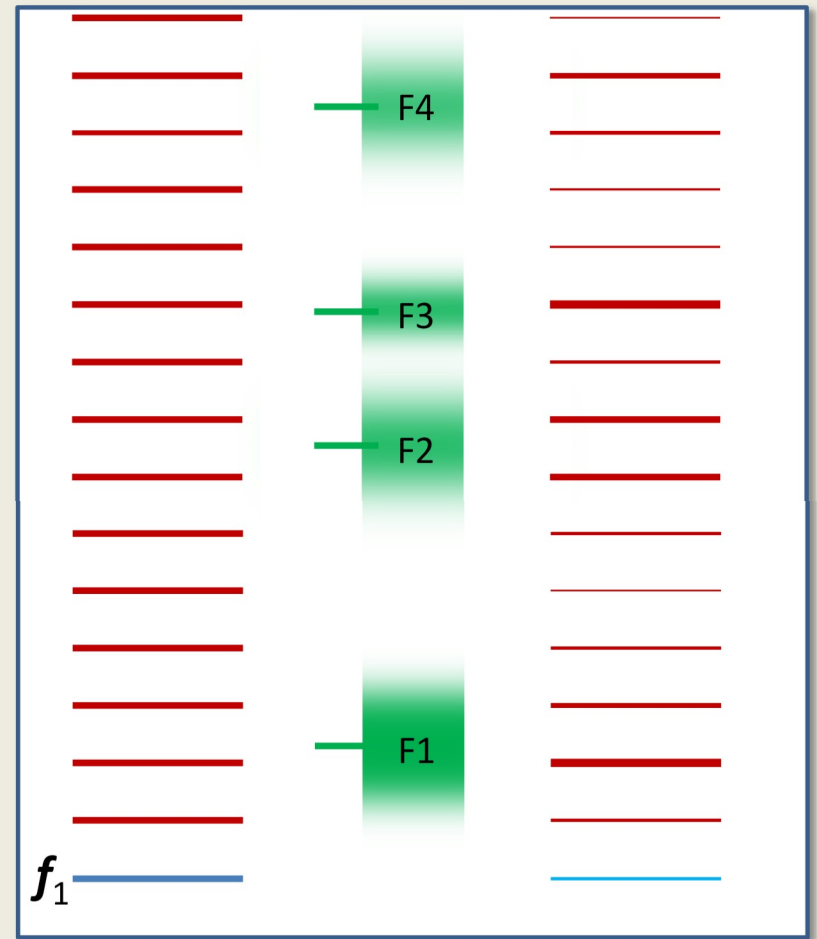
Vocal Tract  
Resonances  
**(Formants)**

Result

# The Vocal Tract Modifies the Sound



Frequency ↑

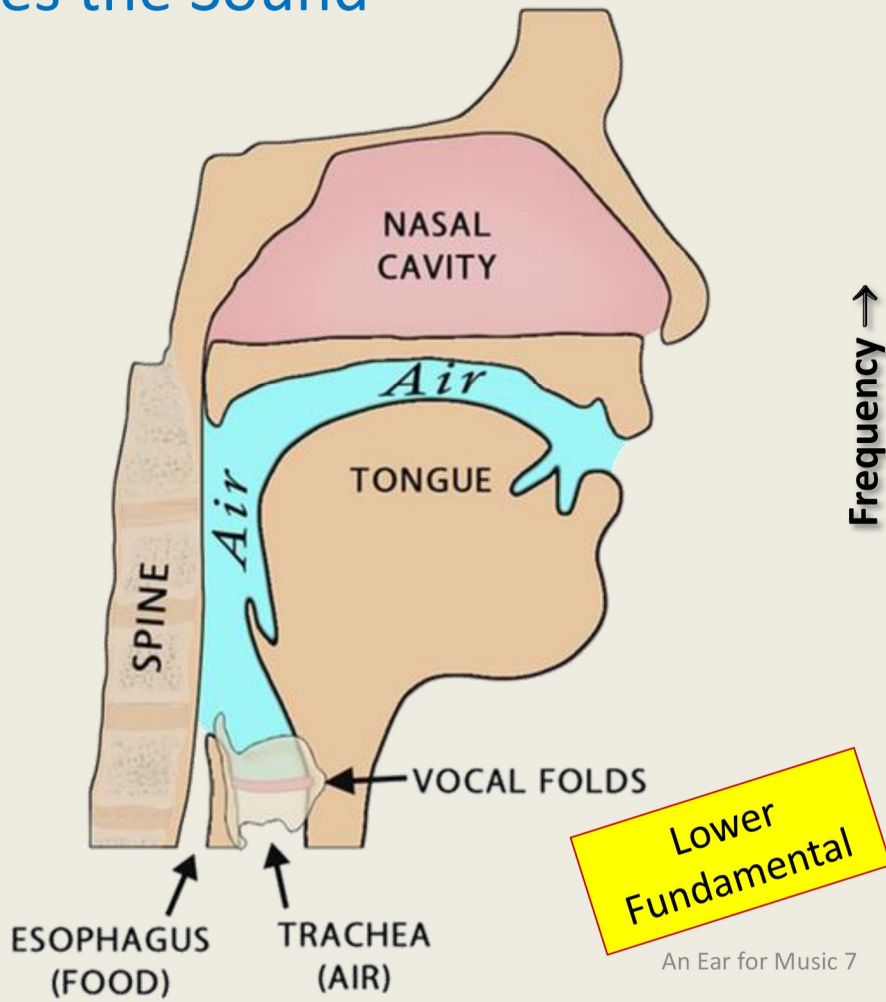


Vocal Folds

Vocal Tract Resonances (Formants)

Result

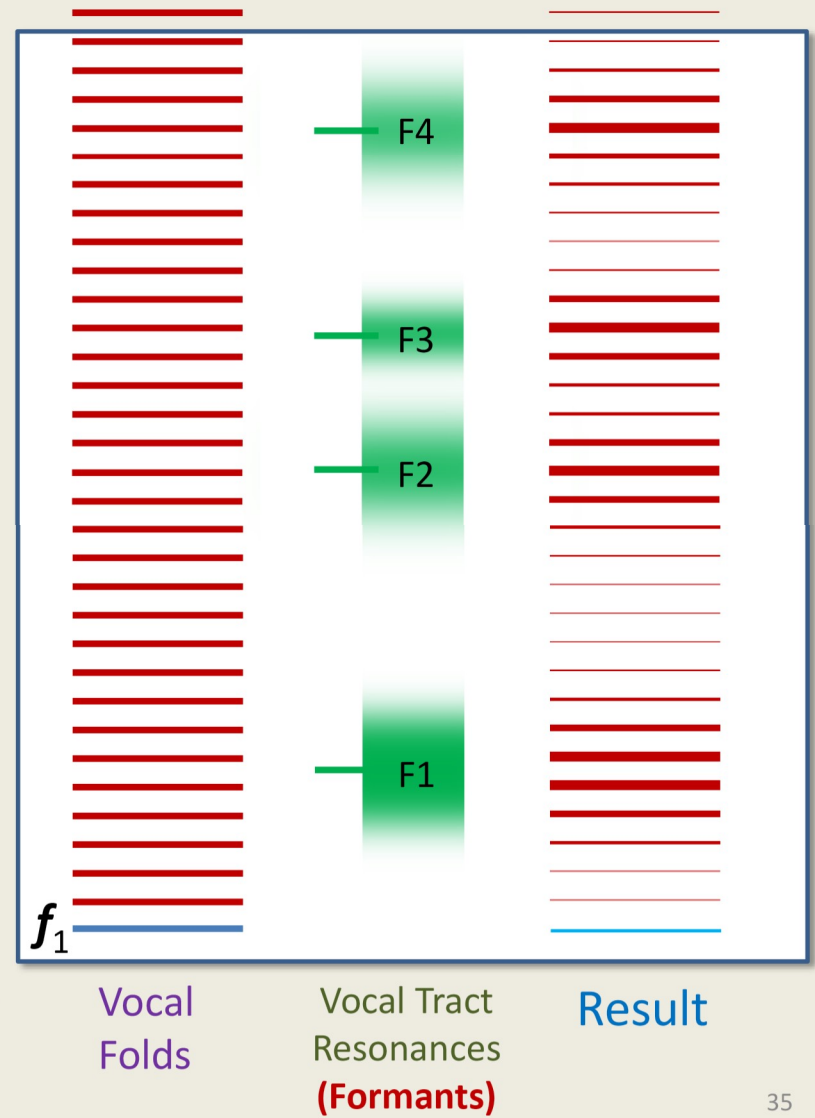
# The Vocal Tract Modifies the Sound



4/12/20

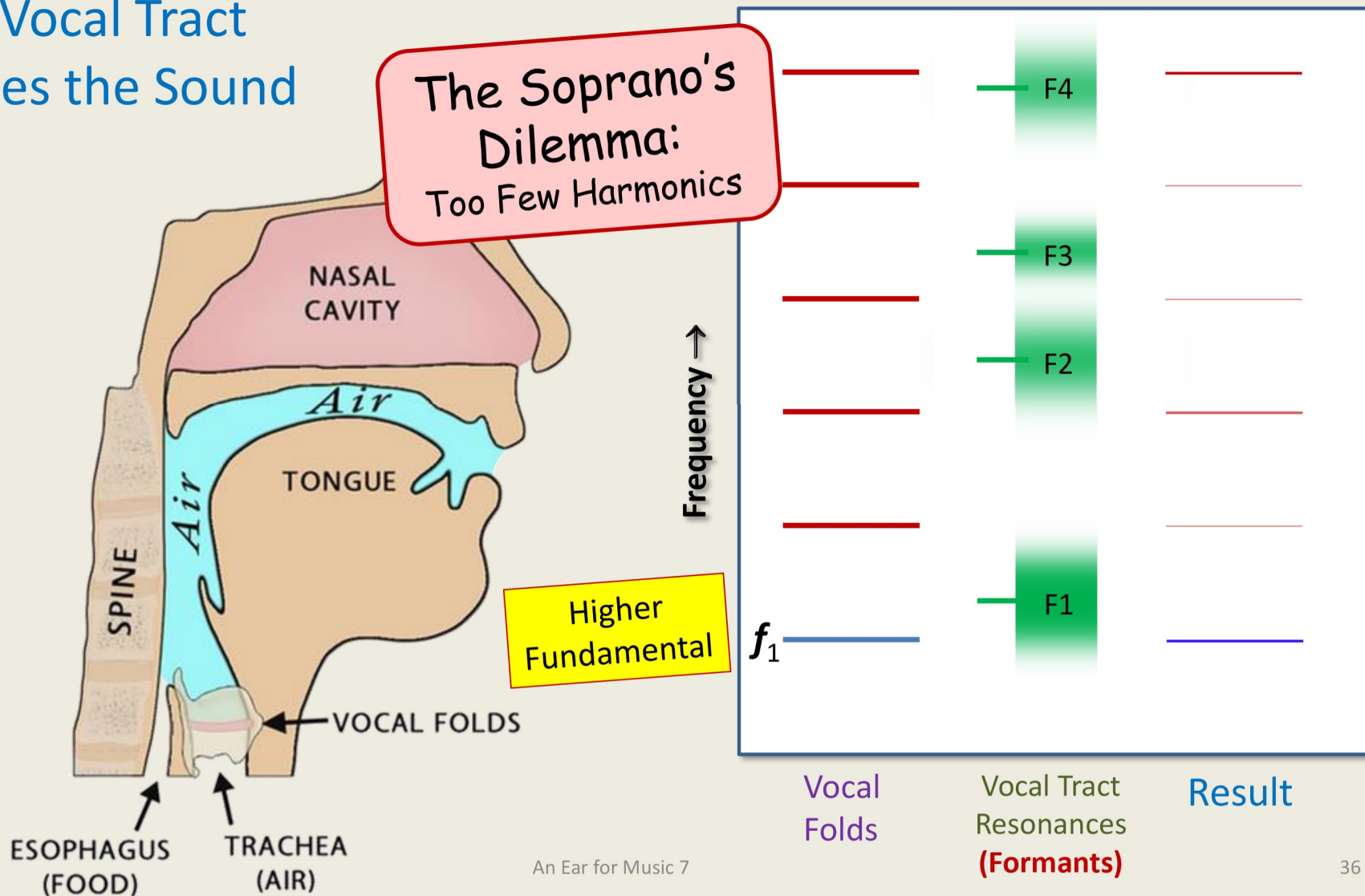
An Ear for Music 7

Frequency ↑



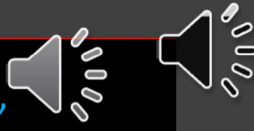


# The Vocal Tract Modifies the Sound

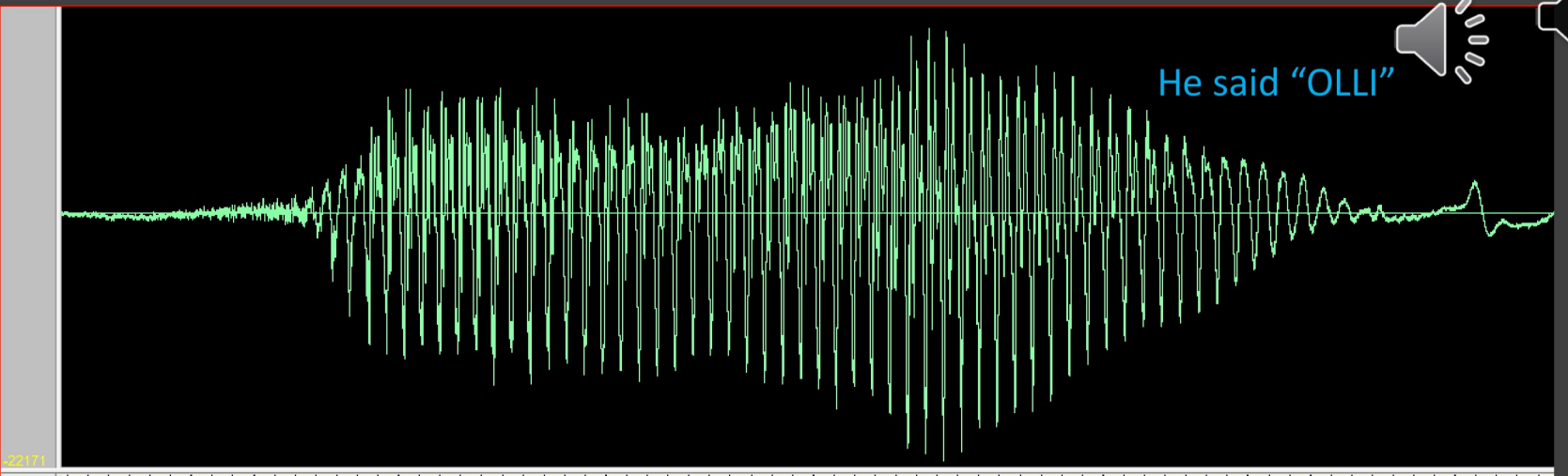


# Speaking "Olli"

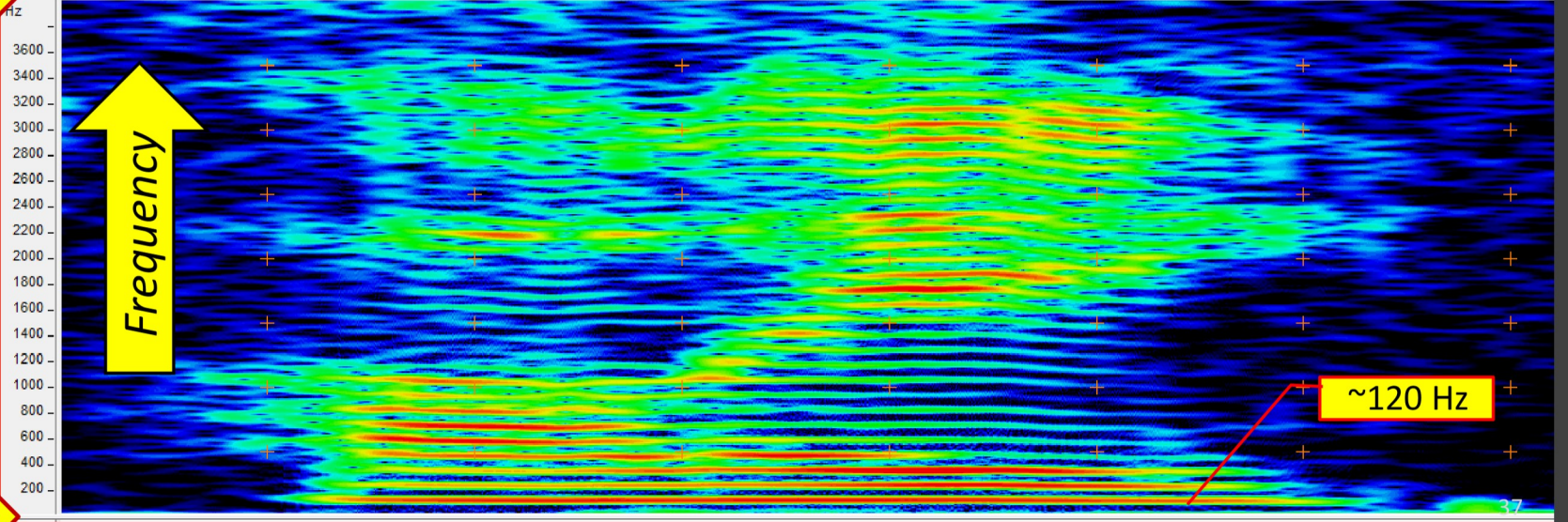
He said "OLLI"



4 kHz



time 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90 0.95



0 Hz

4/12/20



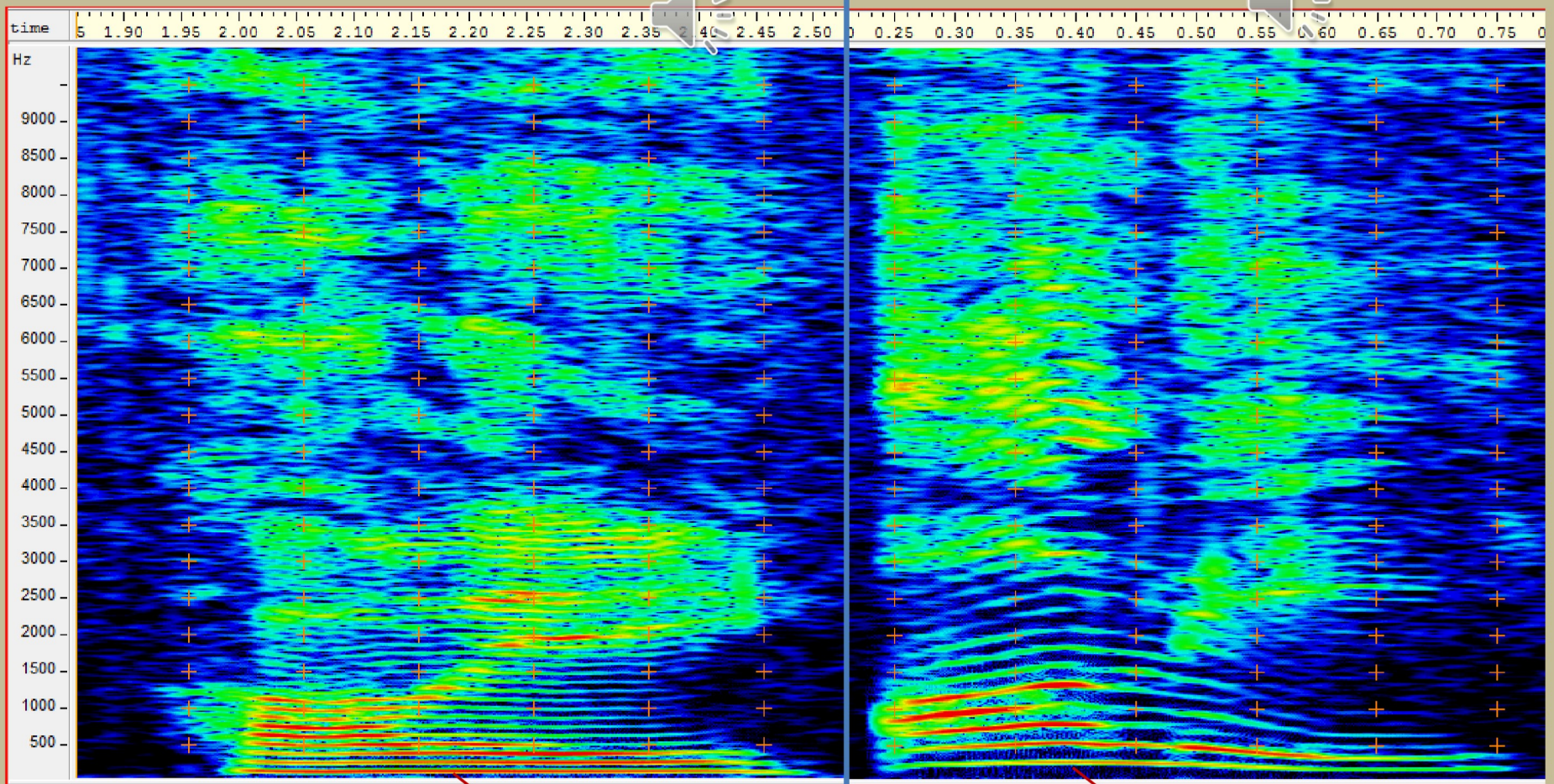


# Speech Formants: "Olli"

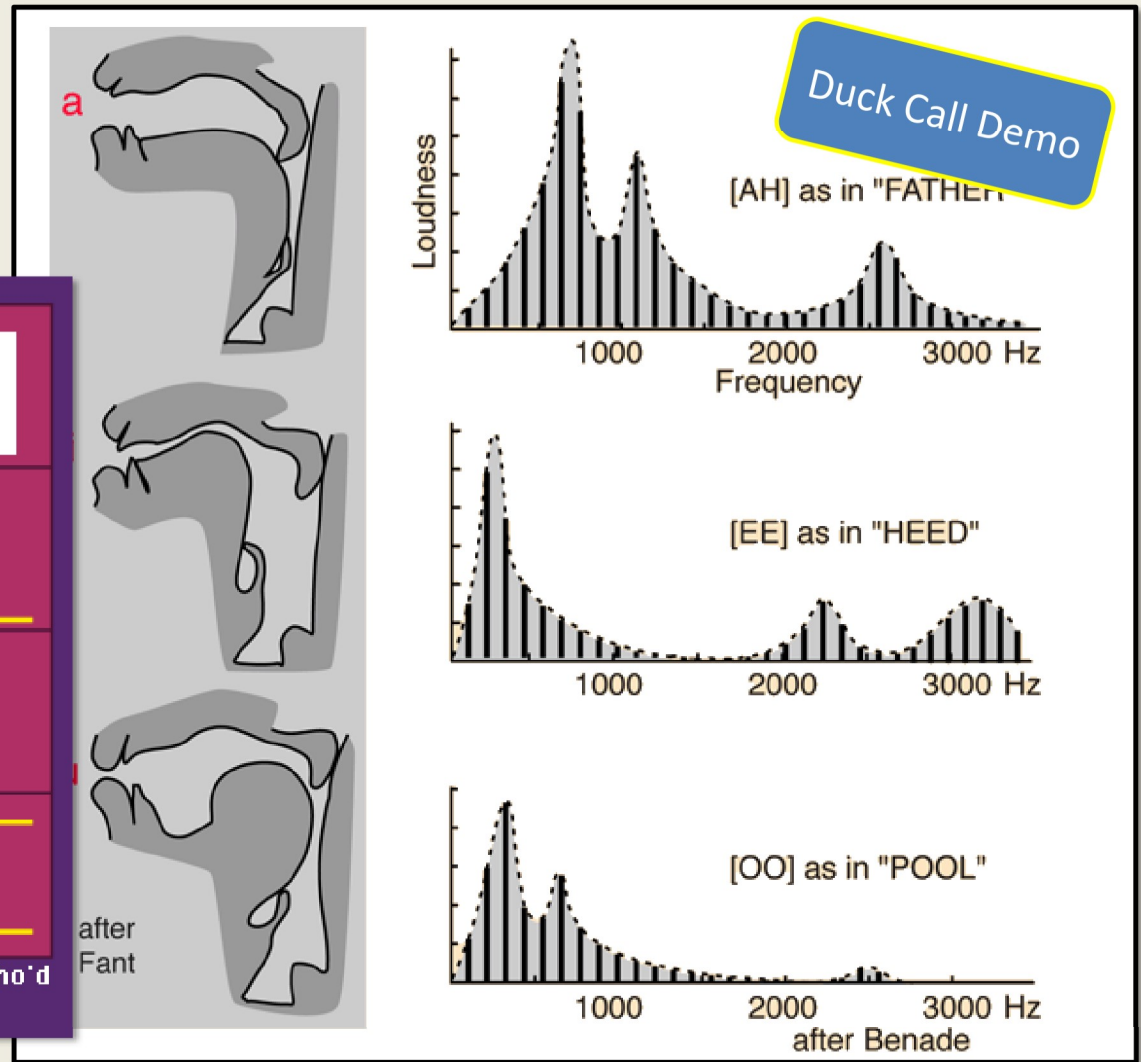
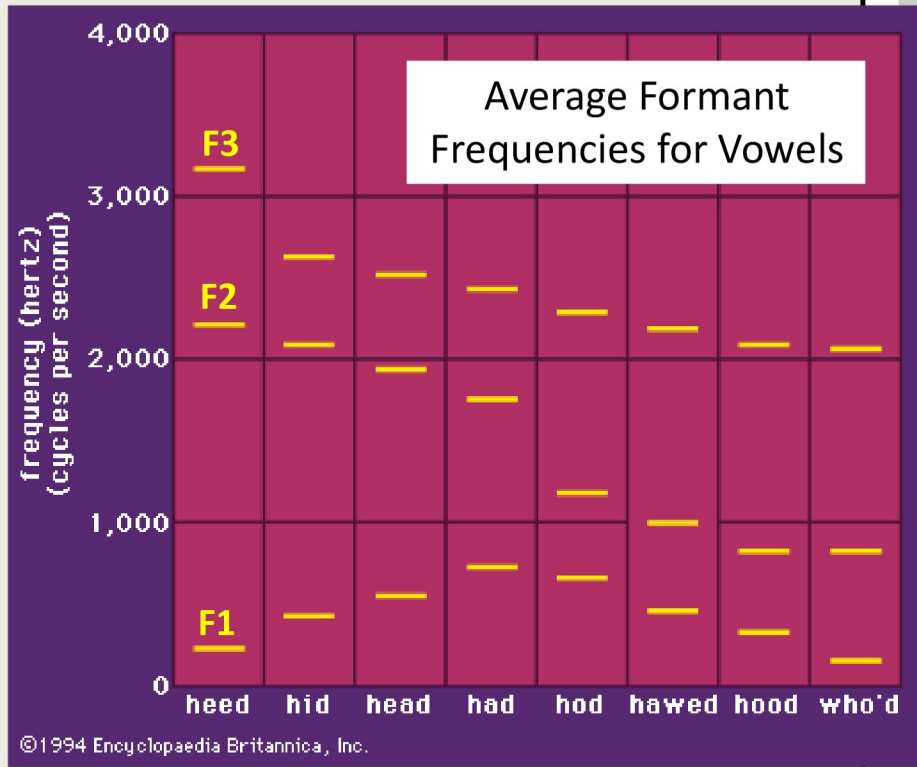


He said "OLLI"

She said "OLLI"

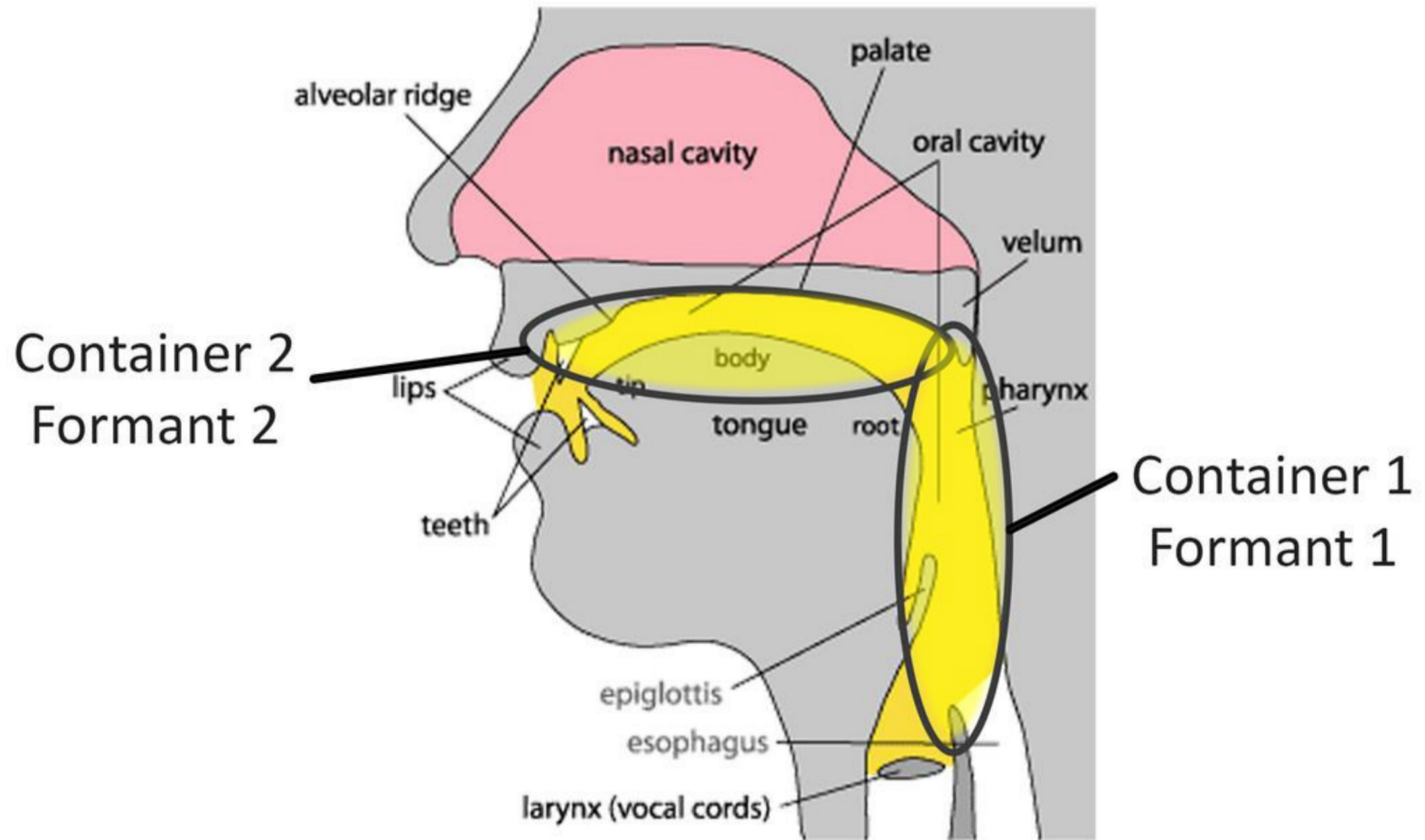


# Harmonics of Voice Fundamental Shaped by Formants

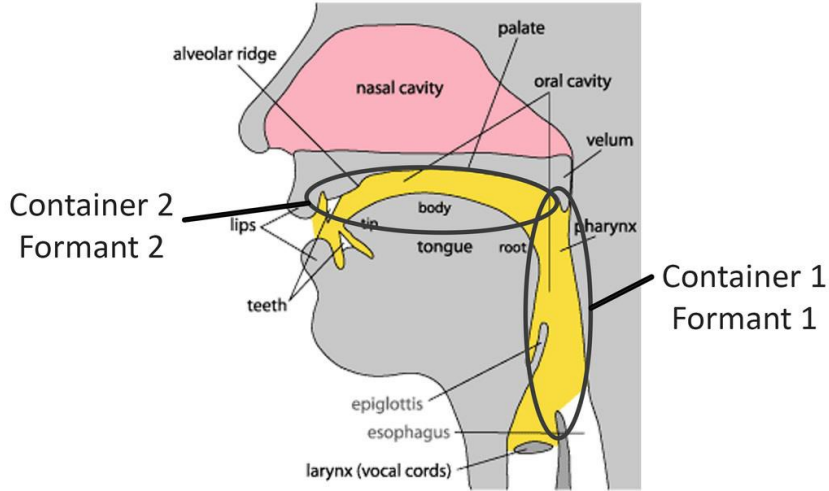
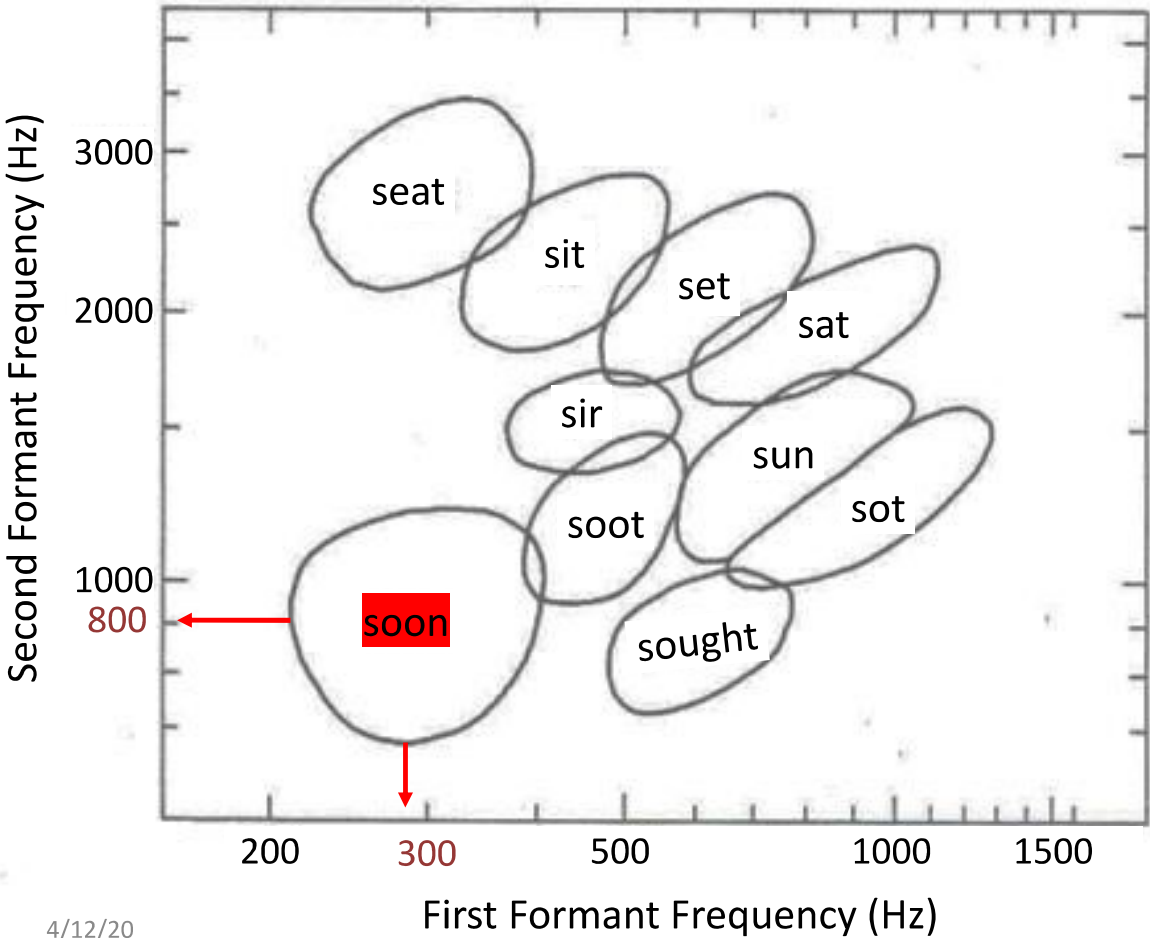




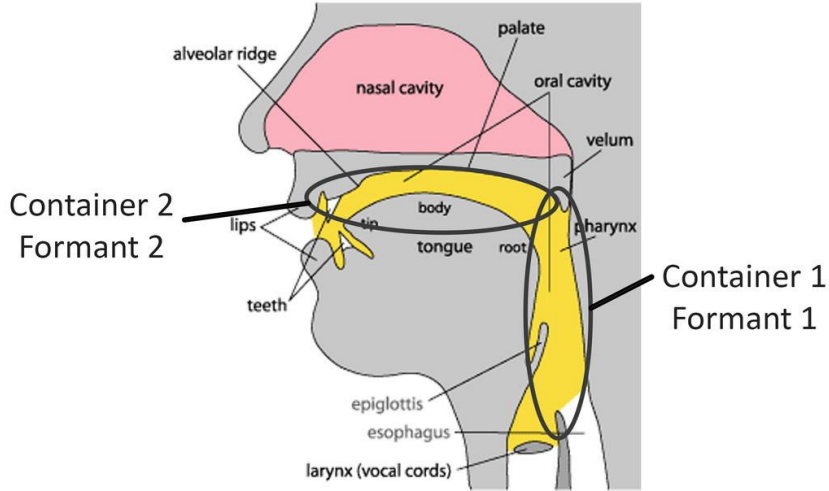
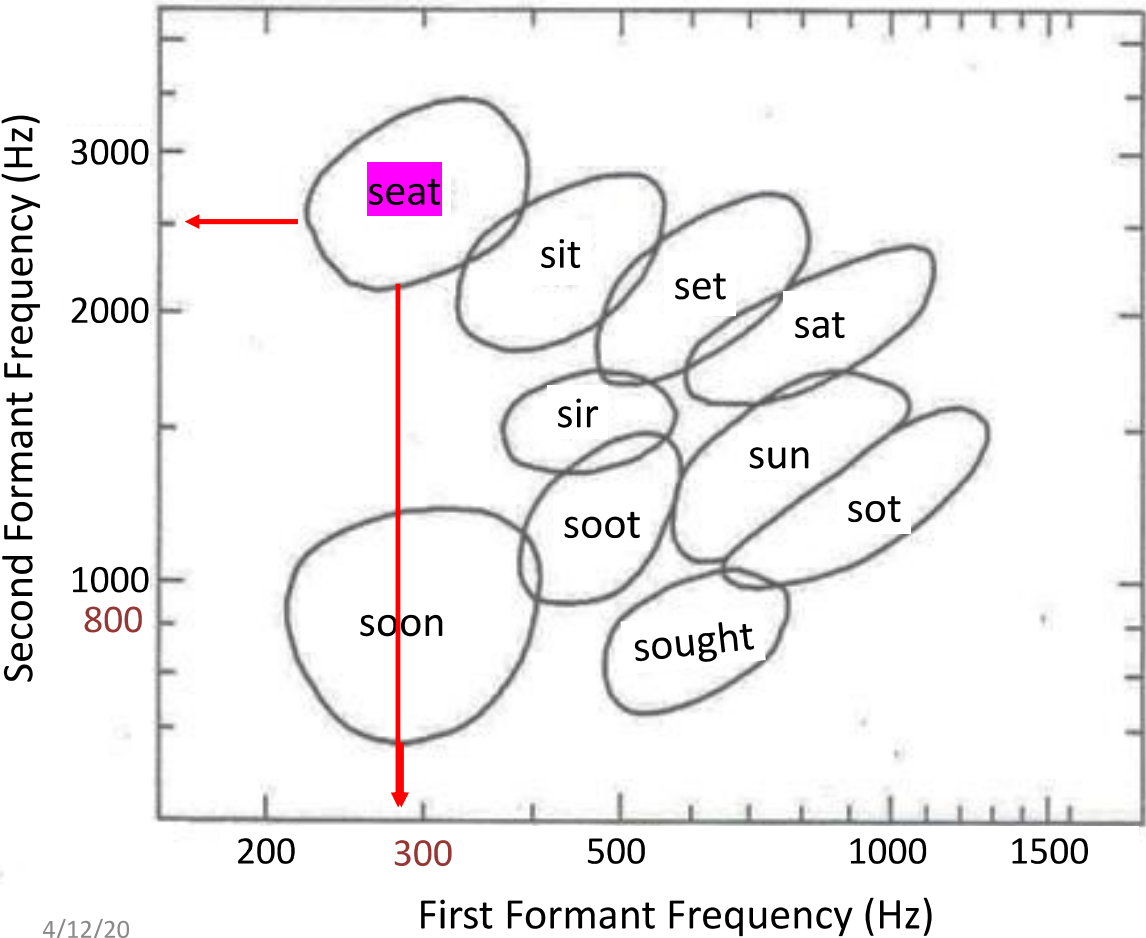
# Approximate Locations of First 2 Formants



# Mapping the Vowels: First 2 Formants



# Mapping the Vowels: First 2 Formants



## Question Time

- Vocal Tract
- Formants



- Zoomland
- In Person





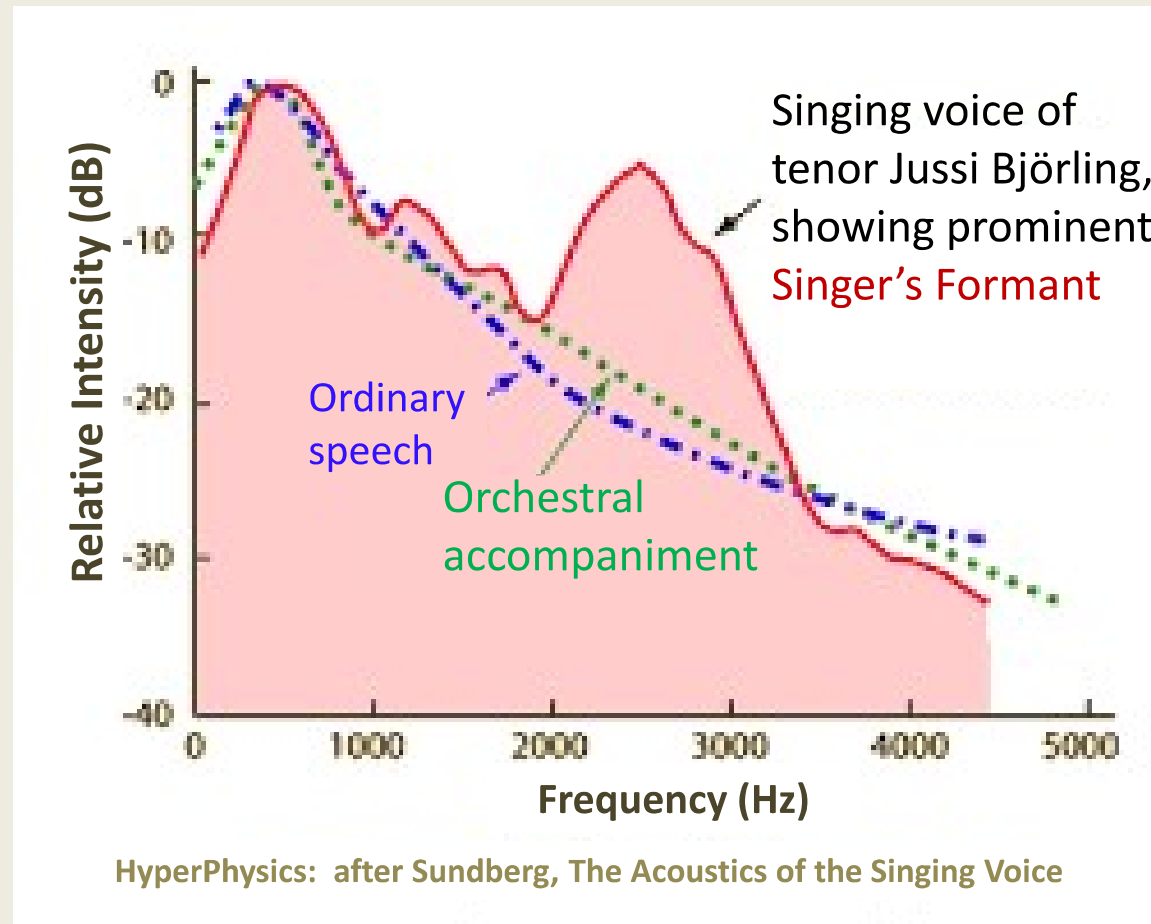
# The “Singer’s Formant”

## To Compete with Orchestra:

Singers try to shift their Vocal Tract Formants to maximize power around 2 to 3 kHz .

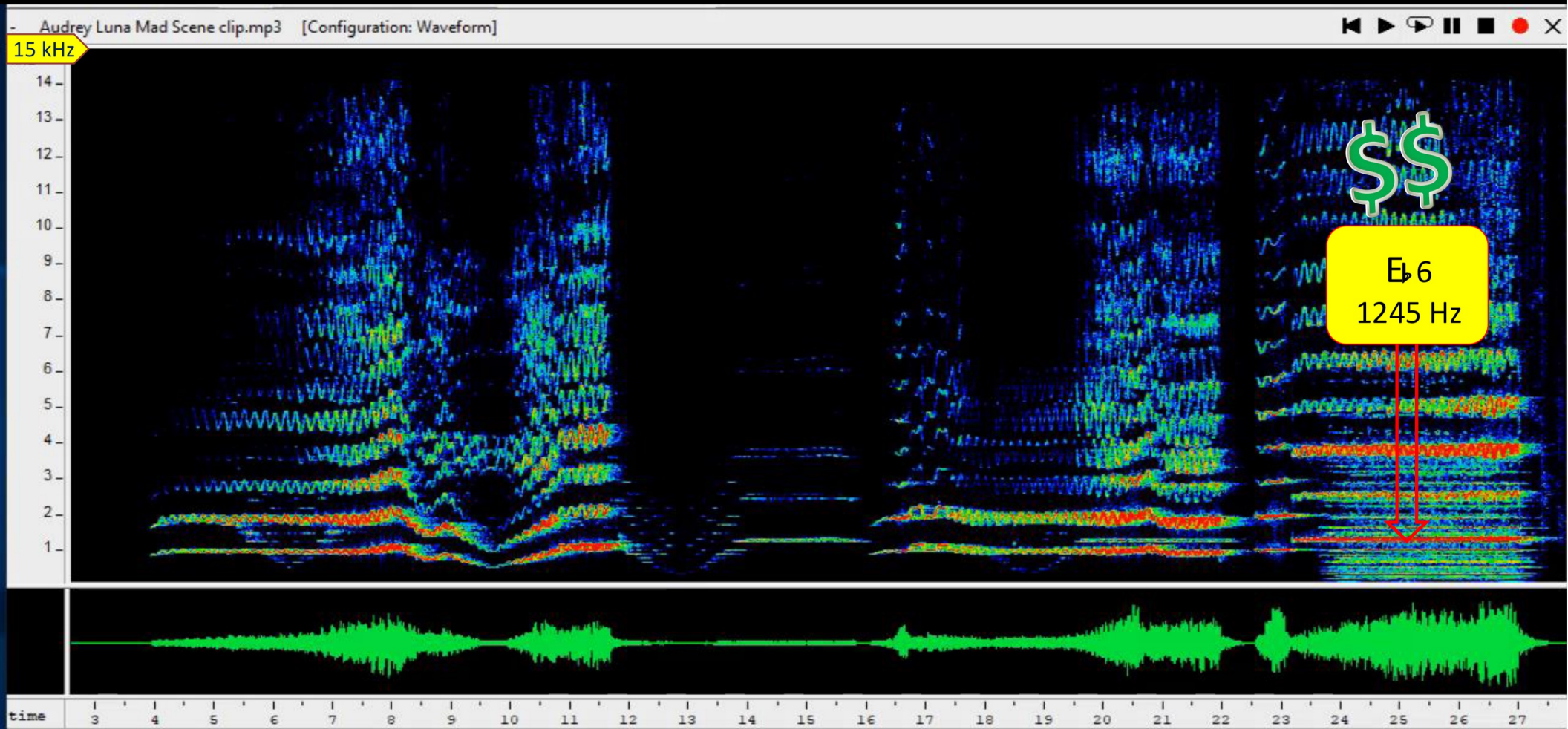
Tricky since each note has *different harmonics* which need to coincide with a Formant.

Even Trickier if lyrics must be understood



1911-1960

# Audrey Luna hits E $\flat$ 6 in *Lucia di Lammermoor*

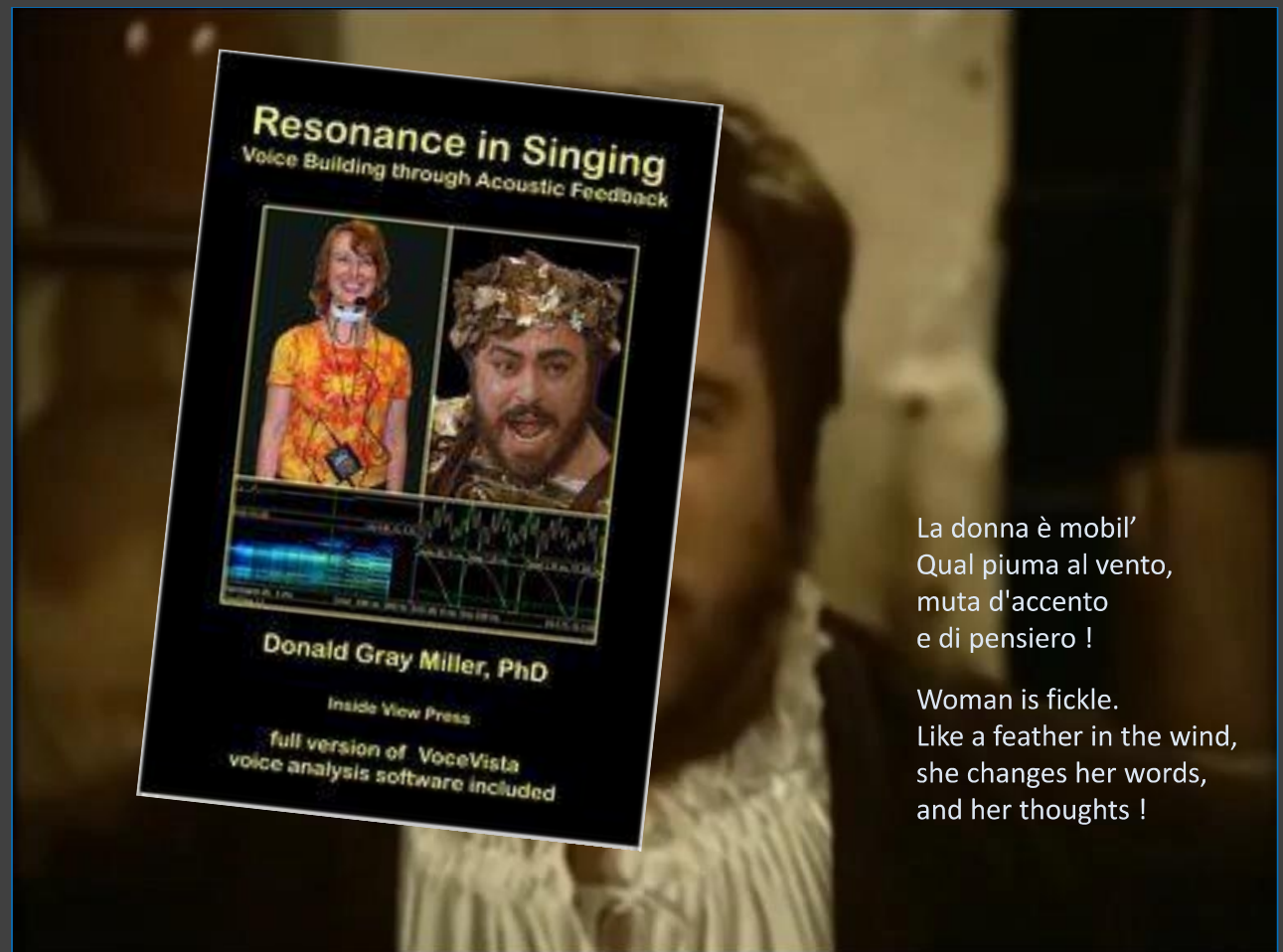


# King of ~~High C's~~

2<sup>nd</sup> Formant  
Tuning\*

Luciano Pavarotti (1935-2007)  
as the Duke of Mantua  
in Verdi's Rigoletto  
singing *La Donna È Mobile*  
Opera Film *Rigoletto* (1982)

\* According to D.G. Miller,  
*Resonance in Singing* (2008)



La donna è mobil'  
Qual piuma al vento,  
muta d'accento  
e di pensiero !

Woman is fickle.  
Like a feather in the wind,  
she changes her words,  
and her thoughts !

# King of ~~High C's~~

2<sup>nd</sup> Formant  
Tuning\*

Luciano Pavarotti (1935-2007)  
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La donna è mobil'  
Woman is fickle



Qual piuma al vento  
Like a feather in the wind  
muta d'accento  
she changes her words  
e di pensier' !  
and her thoughts !

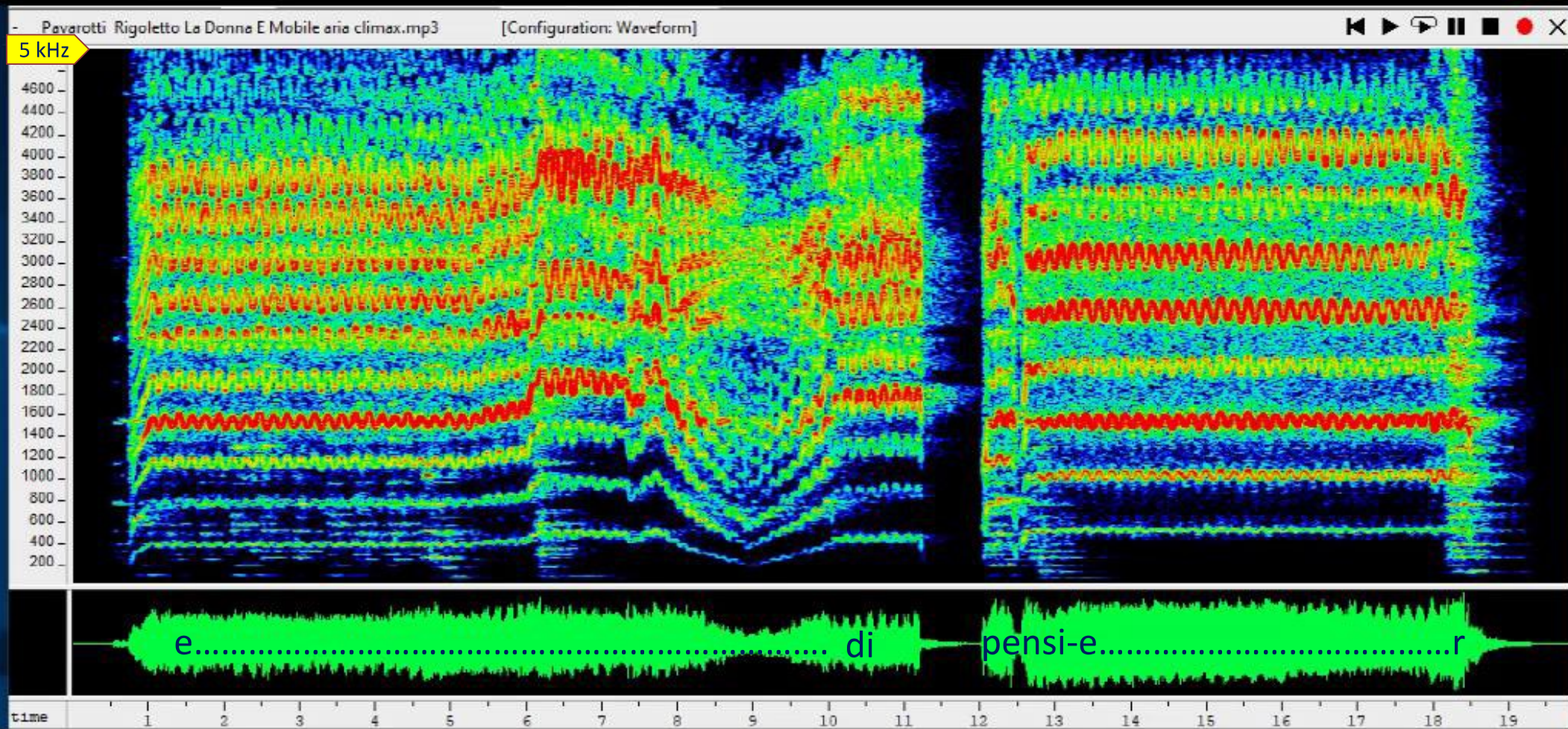
La donna è mobil'  
Qual piuma al vento,  
muta d'accento  
e di pensier'!

Woman is fickle.  
Like a feather in the wind,  
she changes her words,  
and her thoughts!





# Pavarotti: Rigoletto -- La donna è mobile



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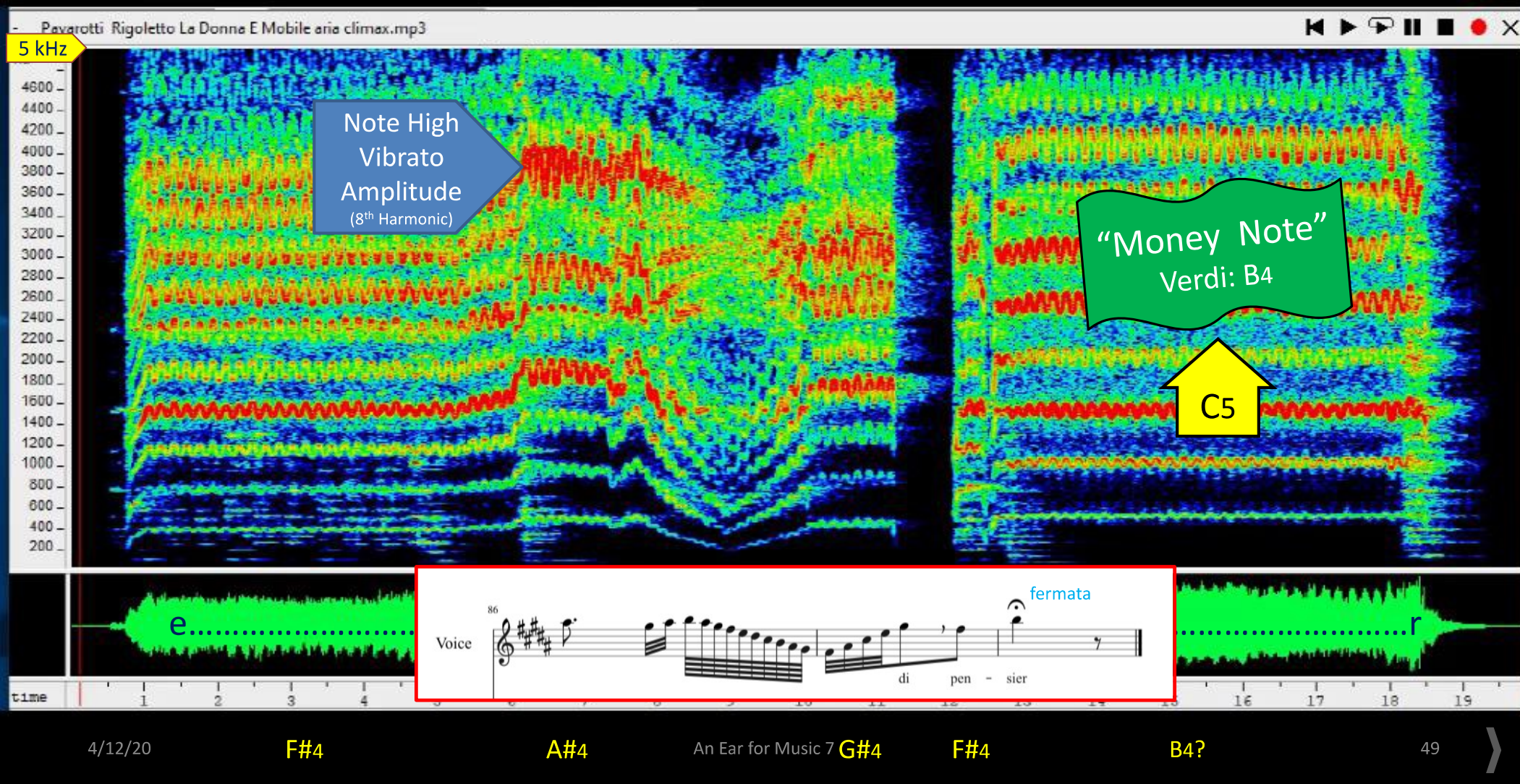
An Ear for Music 7

Luciano Pavarotti (1982)  
*Rigoletto: La donna è mobile* [B Major]

48

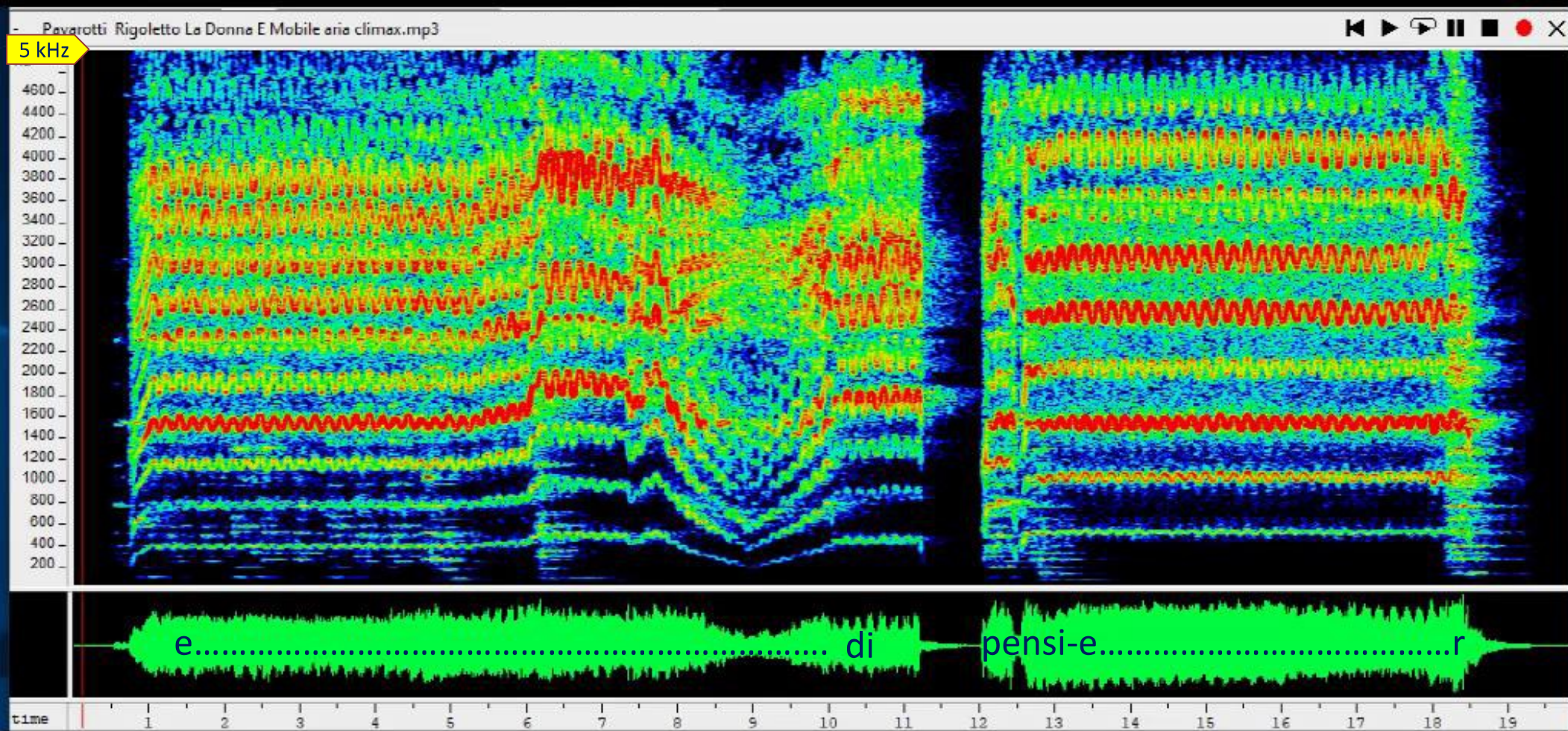


# Pavarotti: Rigoletto -- La donna è mobile





# Pavarotti: Rigoletto – King of 2<sup>nd</sup> Formant Tuning



4/12/20

F#4

A#4

An Ear for Music G#4

F#4

B4?

50

# A Music Lesson



Movie

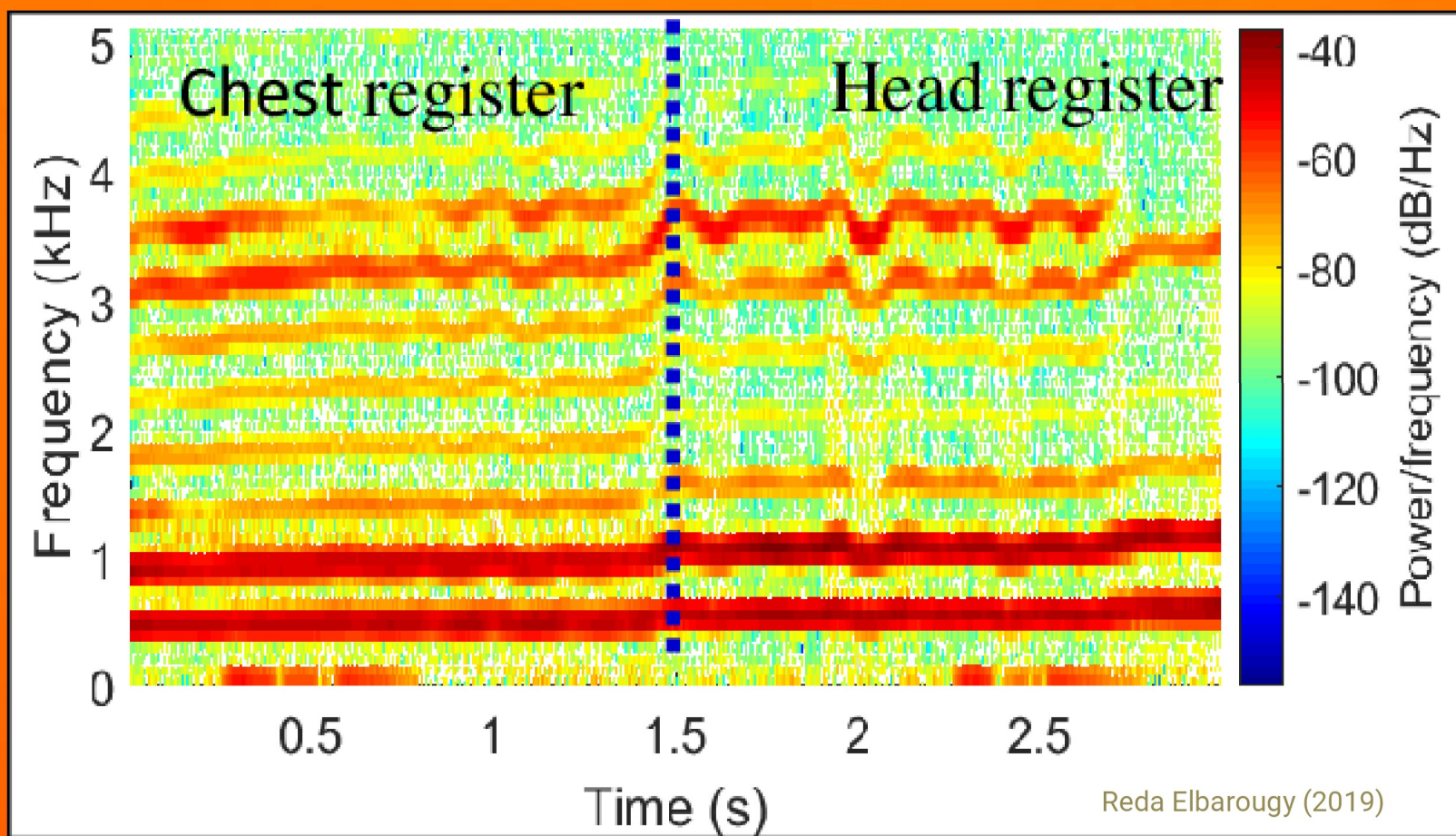


Vocal Warmups for Singing: The 7  
Best Exercises (2018)  
TakeLessons.com





# A Music Lesson

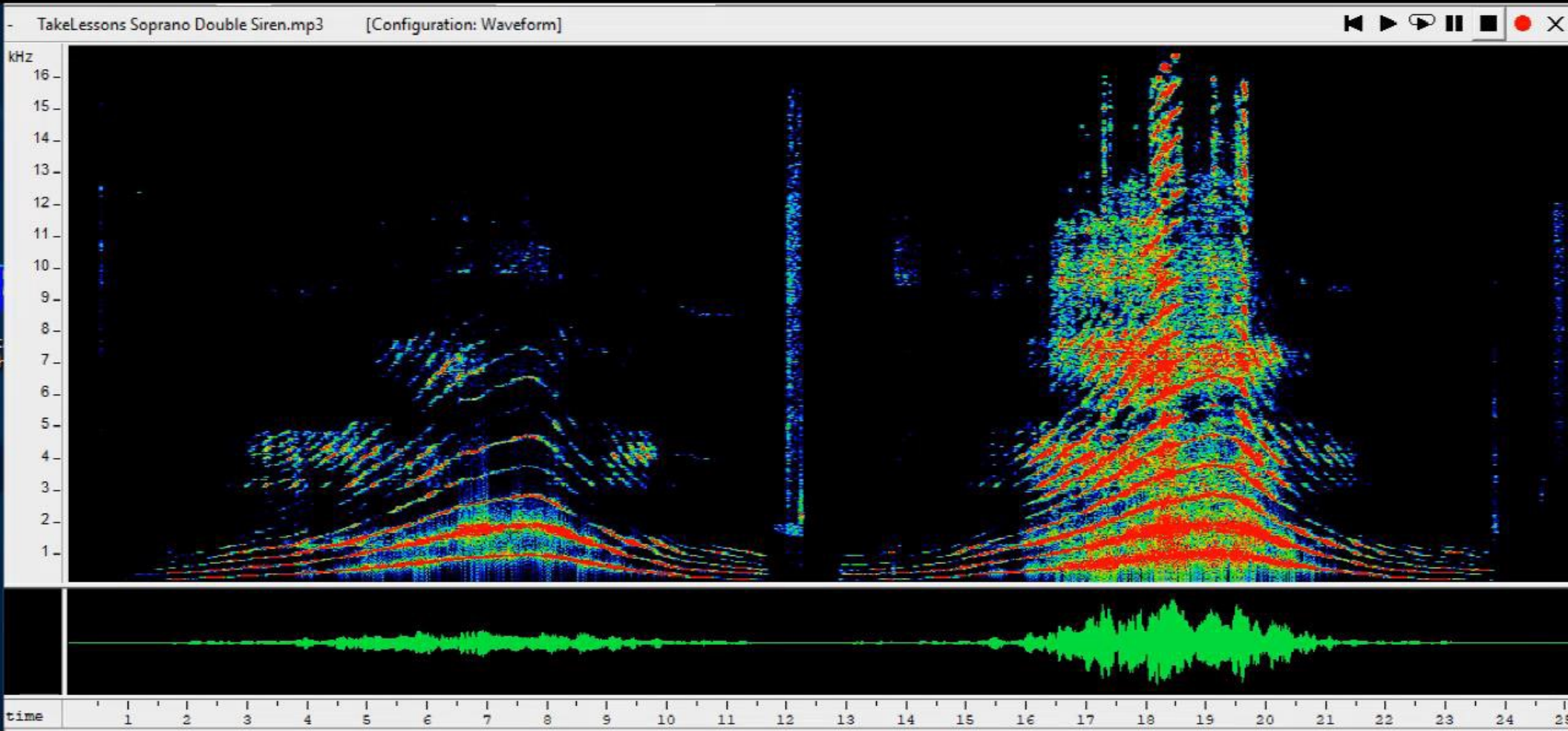


Reda Elbarougy (2019)

Warmups for Singing: The 7  
Best Exercises (2018)  
TakeLessons.com

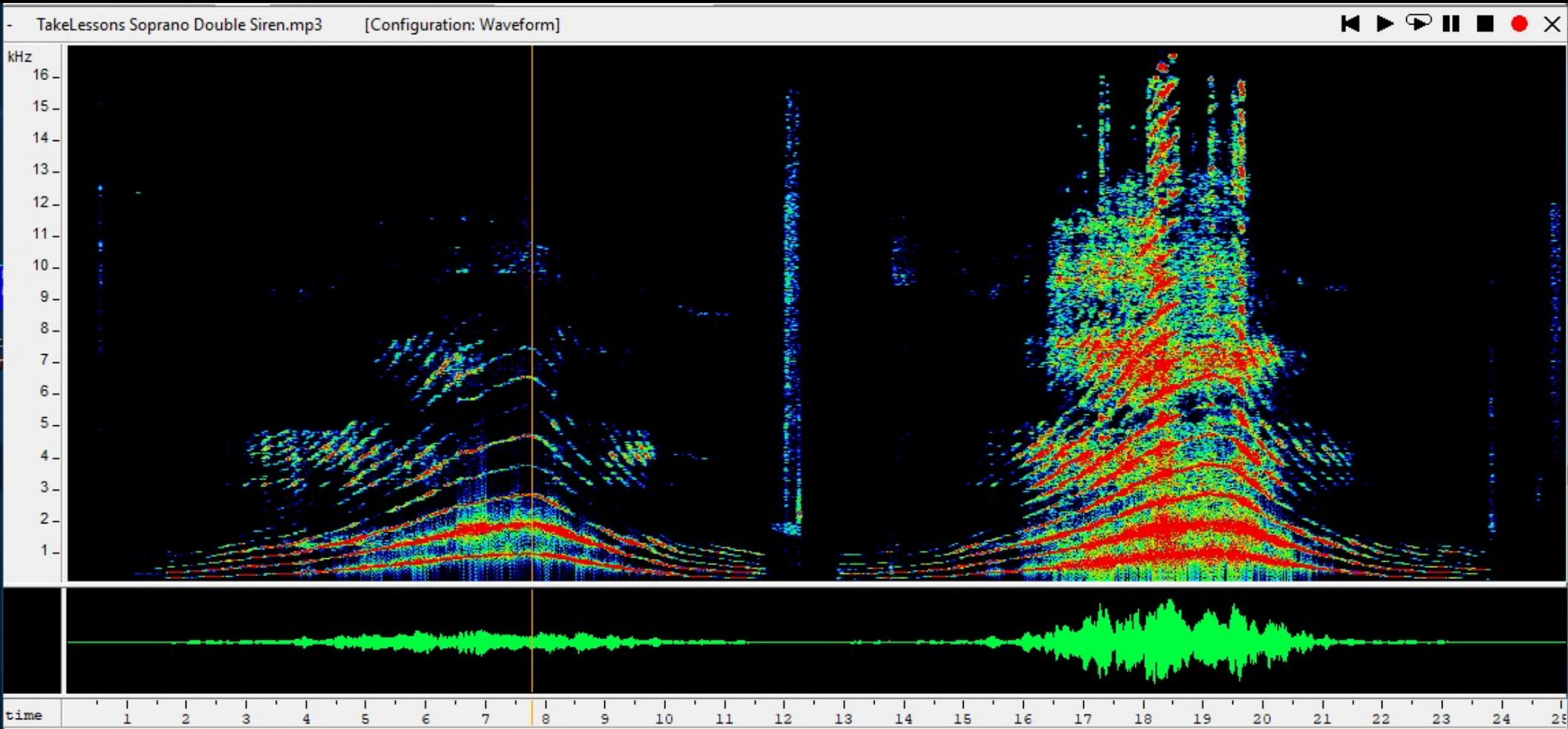


# "Siren"

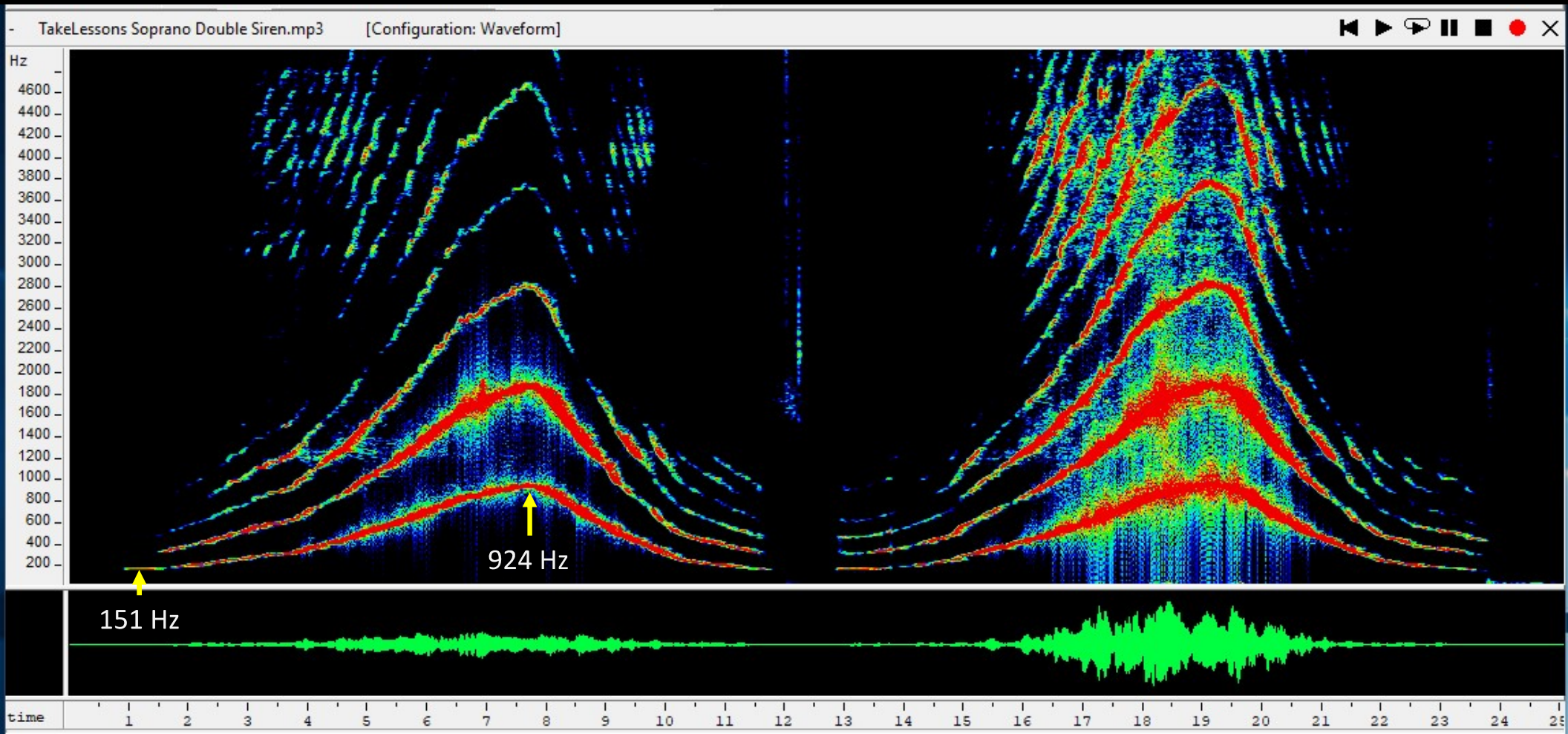




# "Siren"



# "Siren"







# Solfege Diatonic Major Scale

Movie



Note that Solfege syllables have

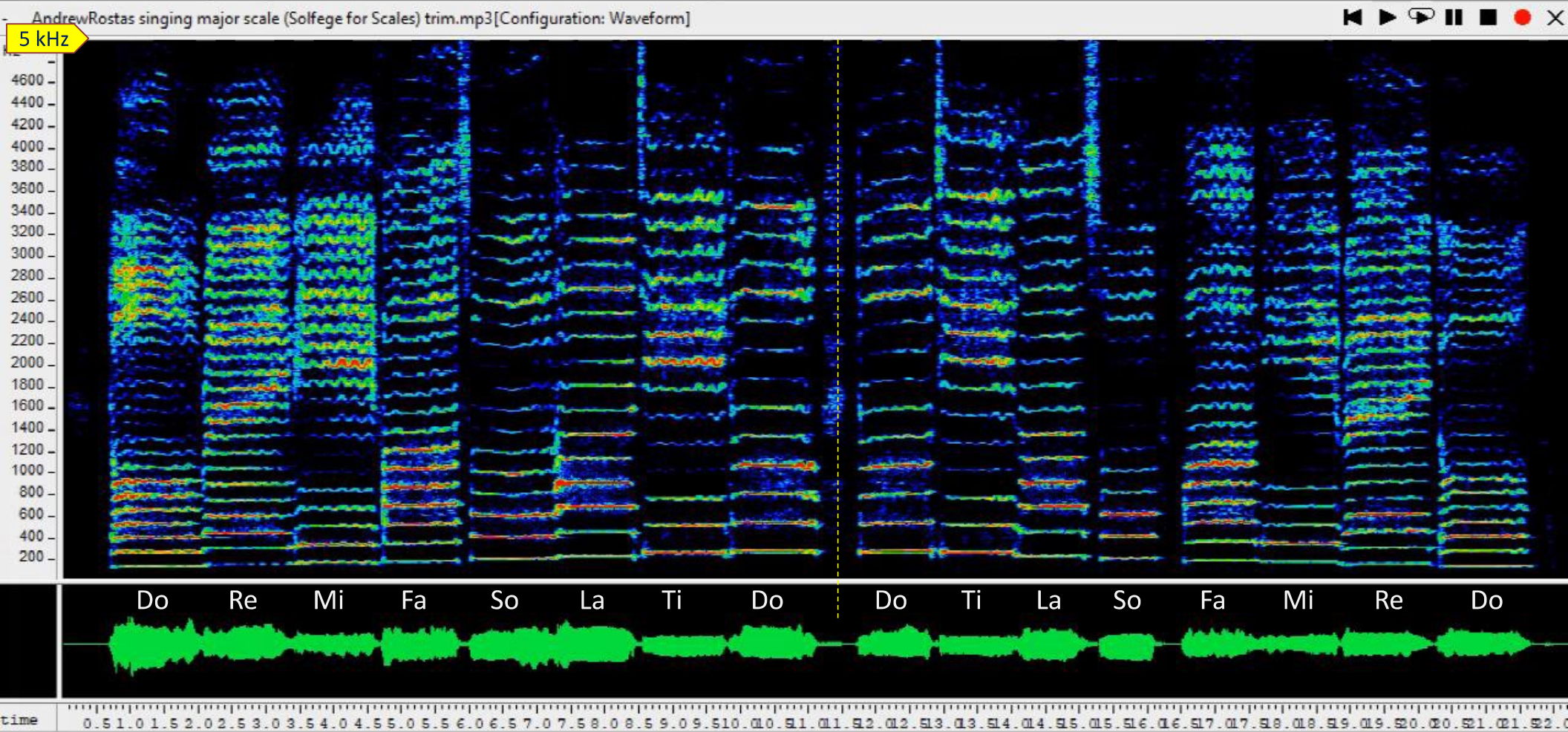
1. different **sung notes** *and*
2. different **vowels**

Andrew Rostas

*Solfege Tutorial – Video 1 (2016)*

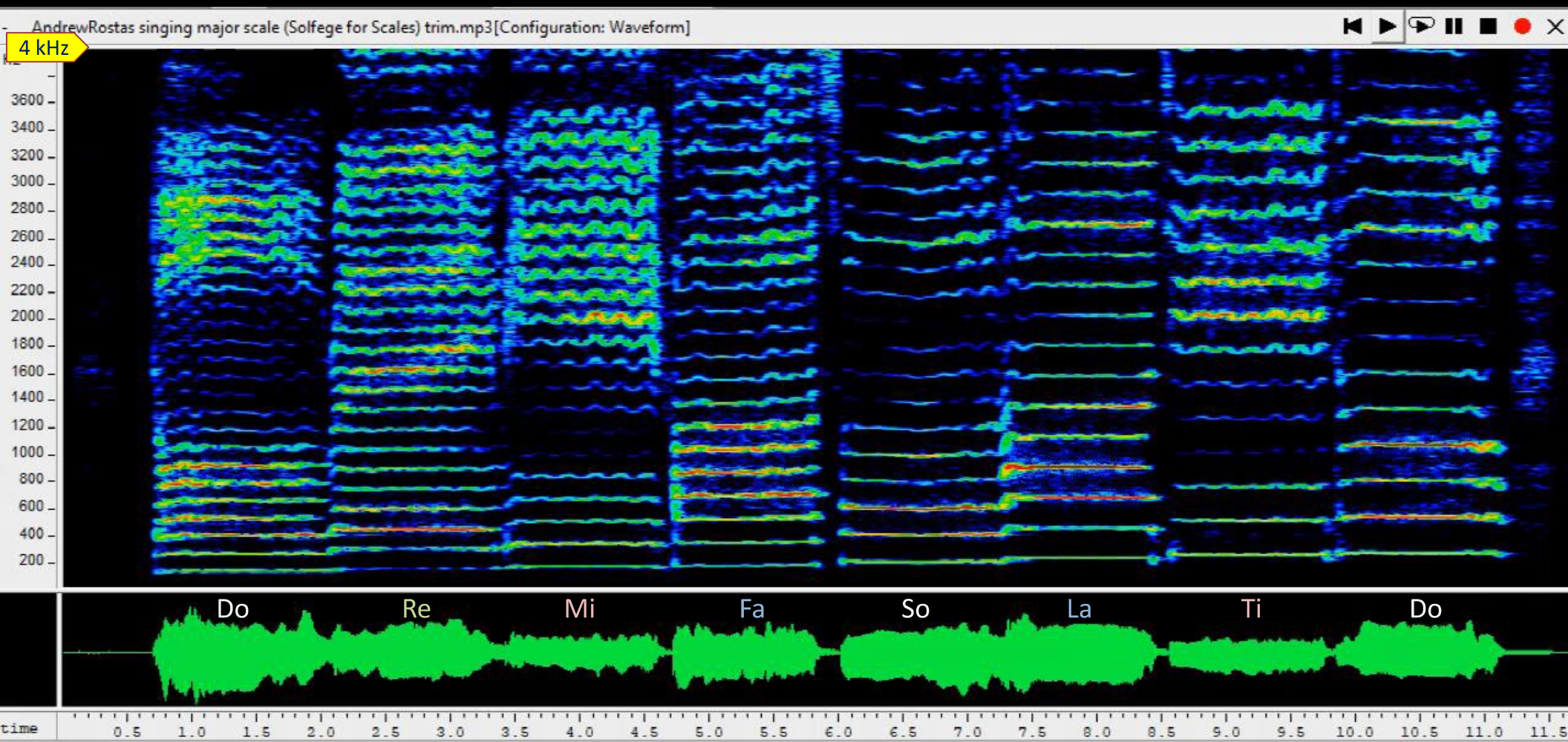


# Solfege: Diatonic C Major Scale [ C3 to C4 ]

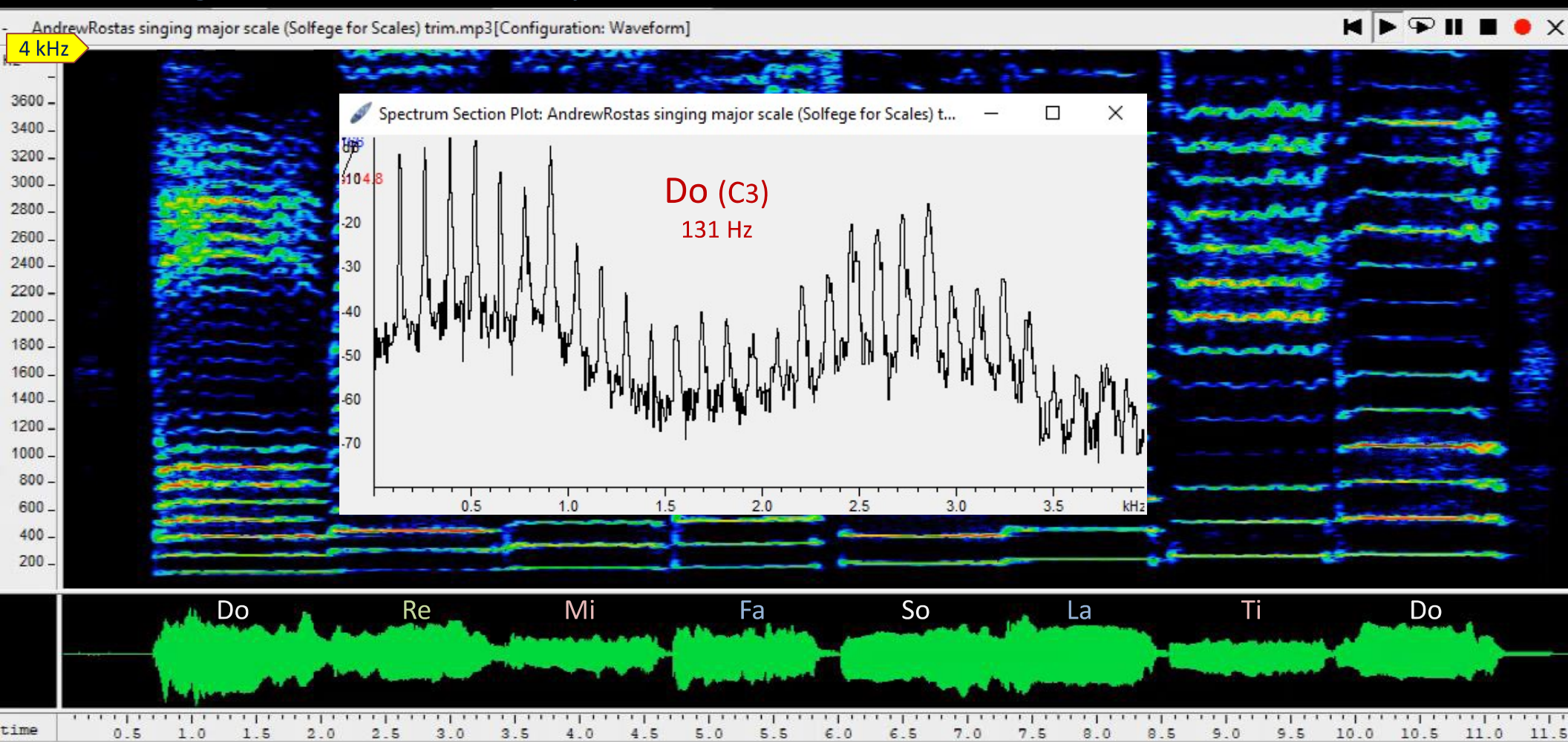




# Solfege: Diatonic C Major Scale [ C3 to C4 ]

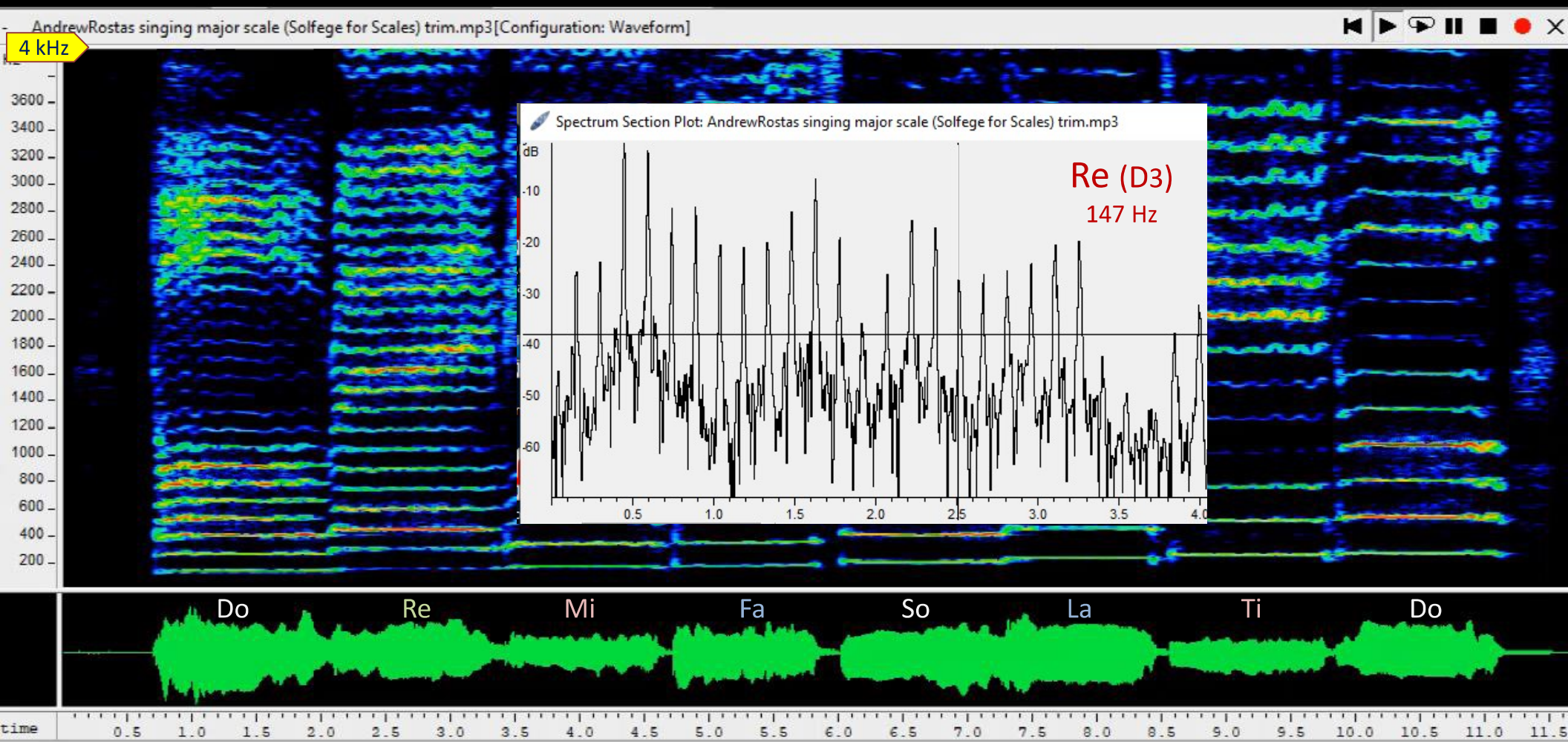


# Solfege: Diatonic C Major Scale [ C3 to C4 ]

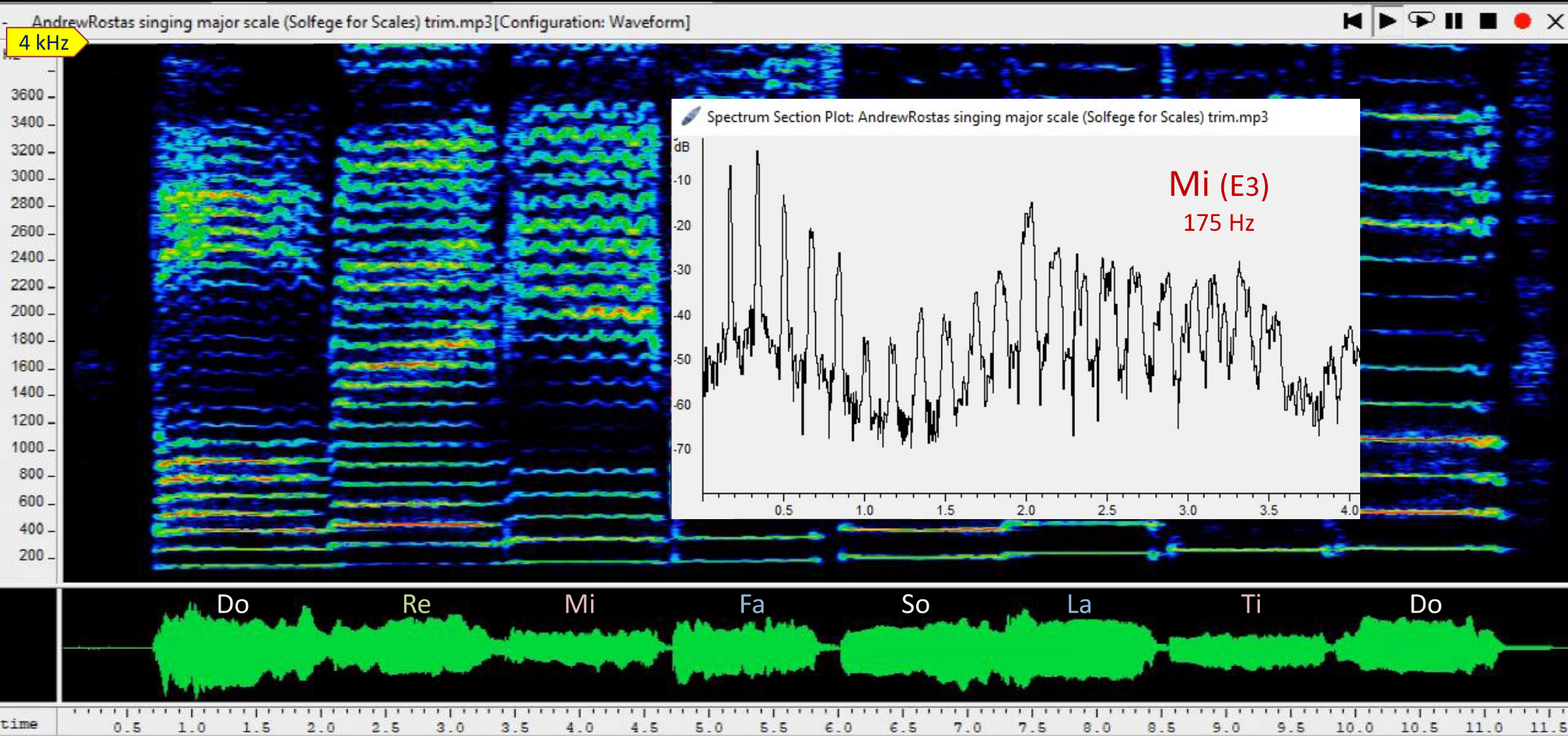




# Solfege: Diatonic C Major Scale [ C3 to C4 ]

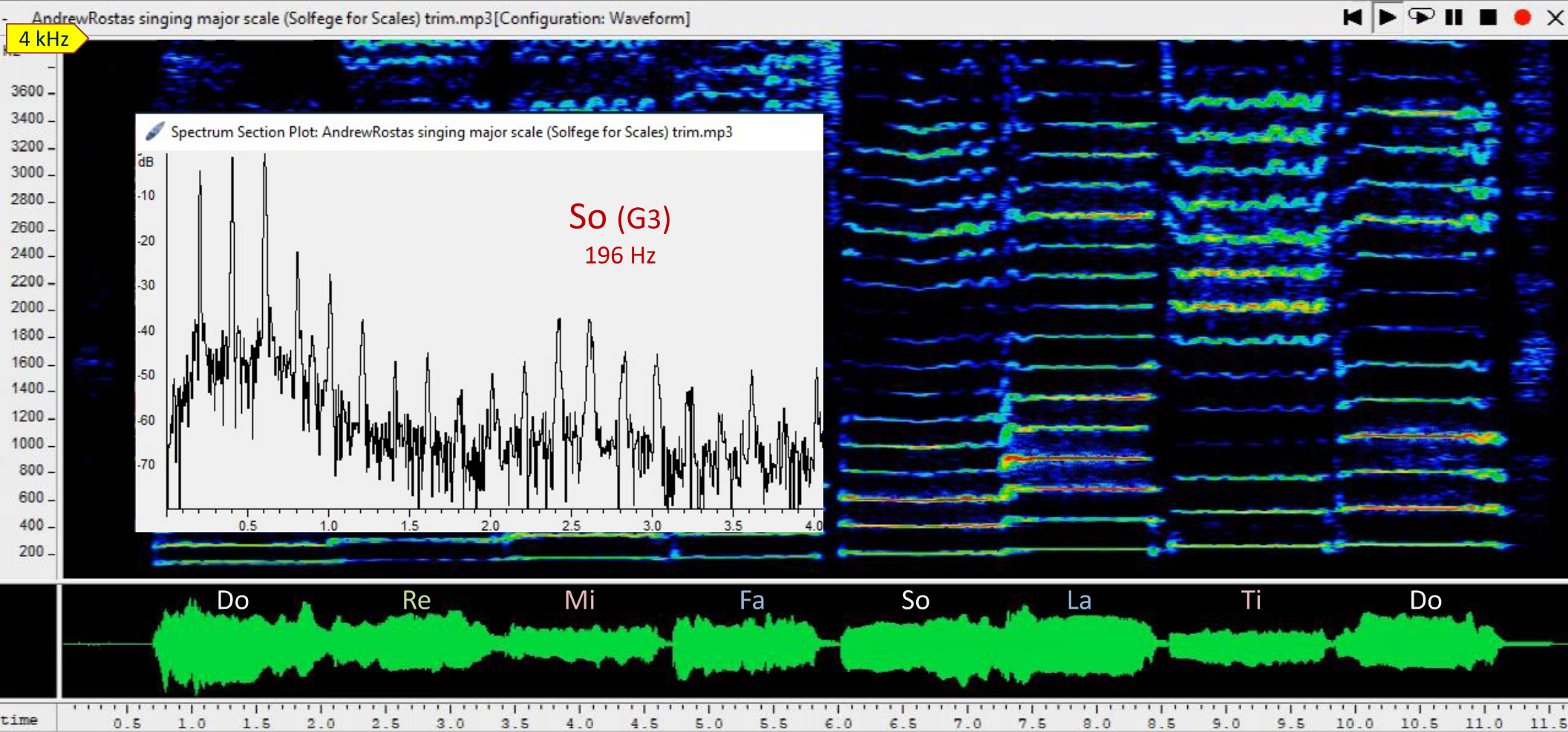


# Solfege: Diatonic C Major Scale [ C3 to C4 ]

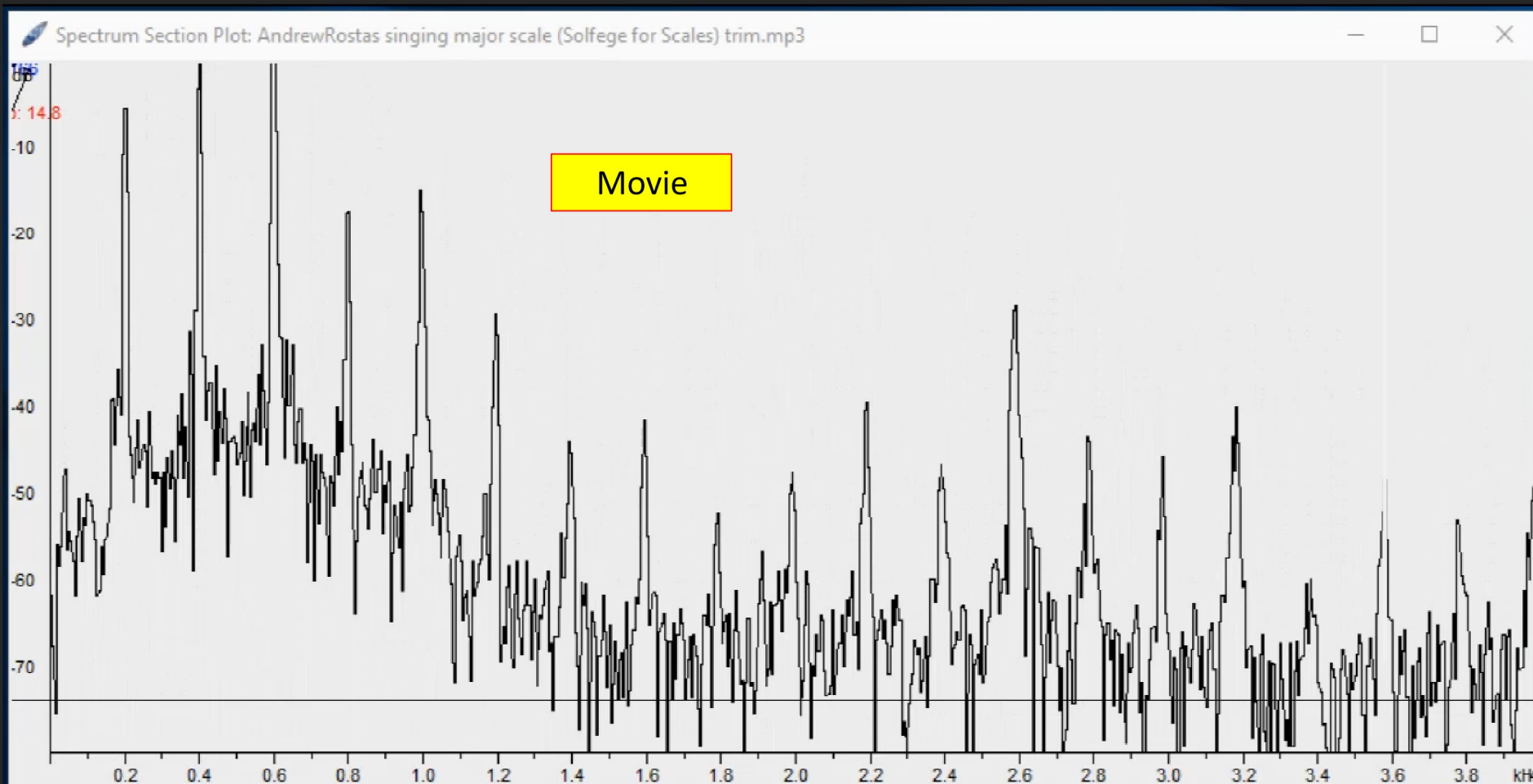




# Solfege: Diatonic C Major Scale [ C3 to C4 ]



# Solfege: Diatonic C Major Scale [ C3 to C4 ]





# Solfege Diatonic Major Scale

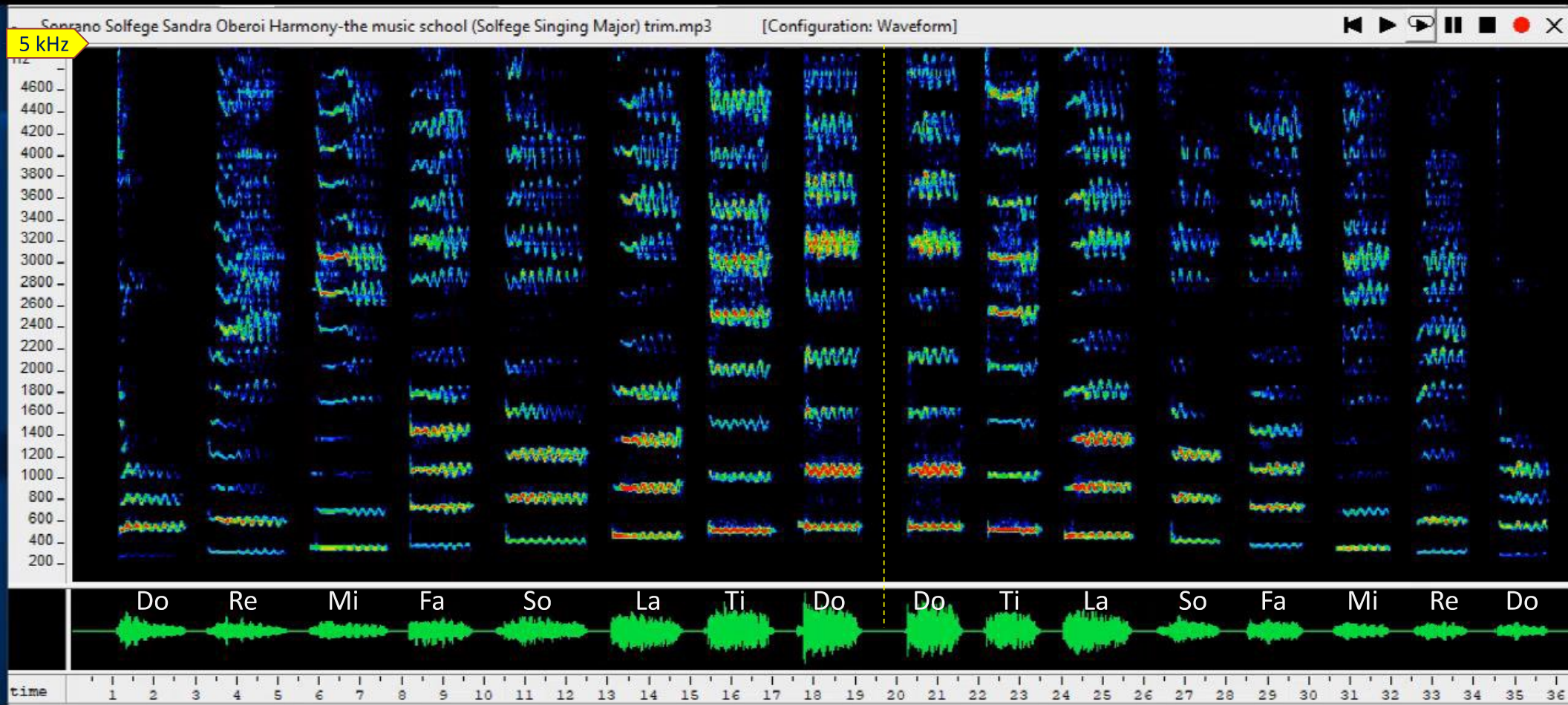
Movie



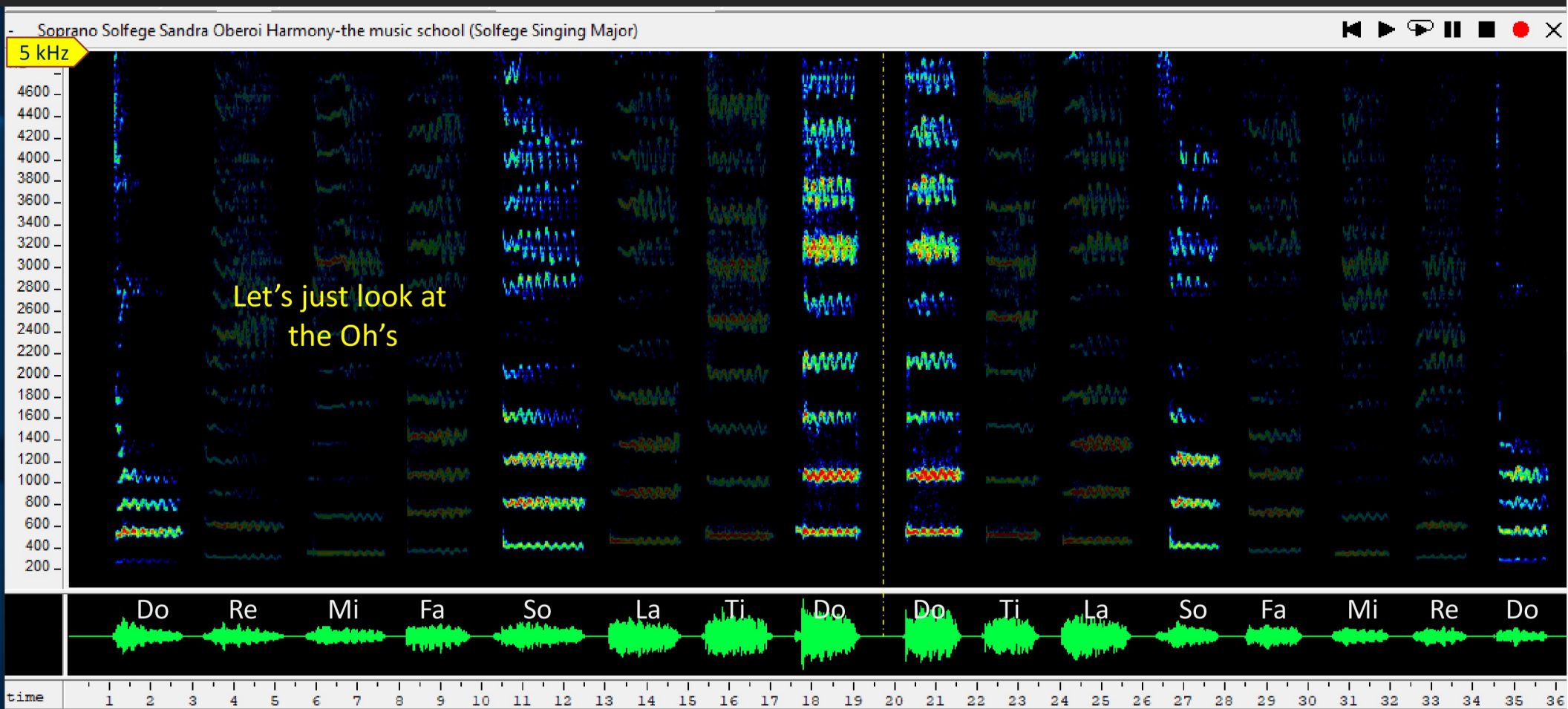
Sandra Oberoi  
*Solfege Singing: Major Scale and  
Intervals (2013)*  
Harmony – the music school



# Solfege: Diatonic C Major Scale [ C4 to C5 ]

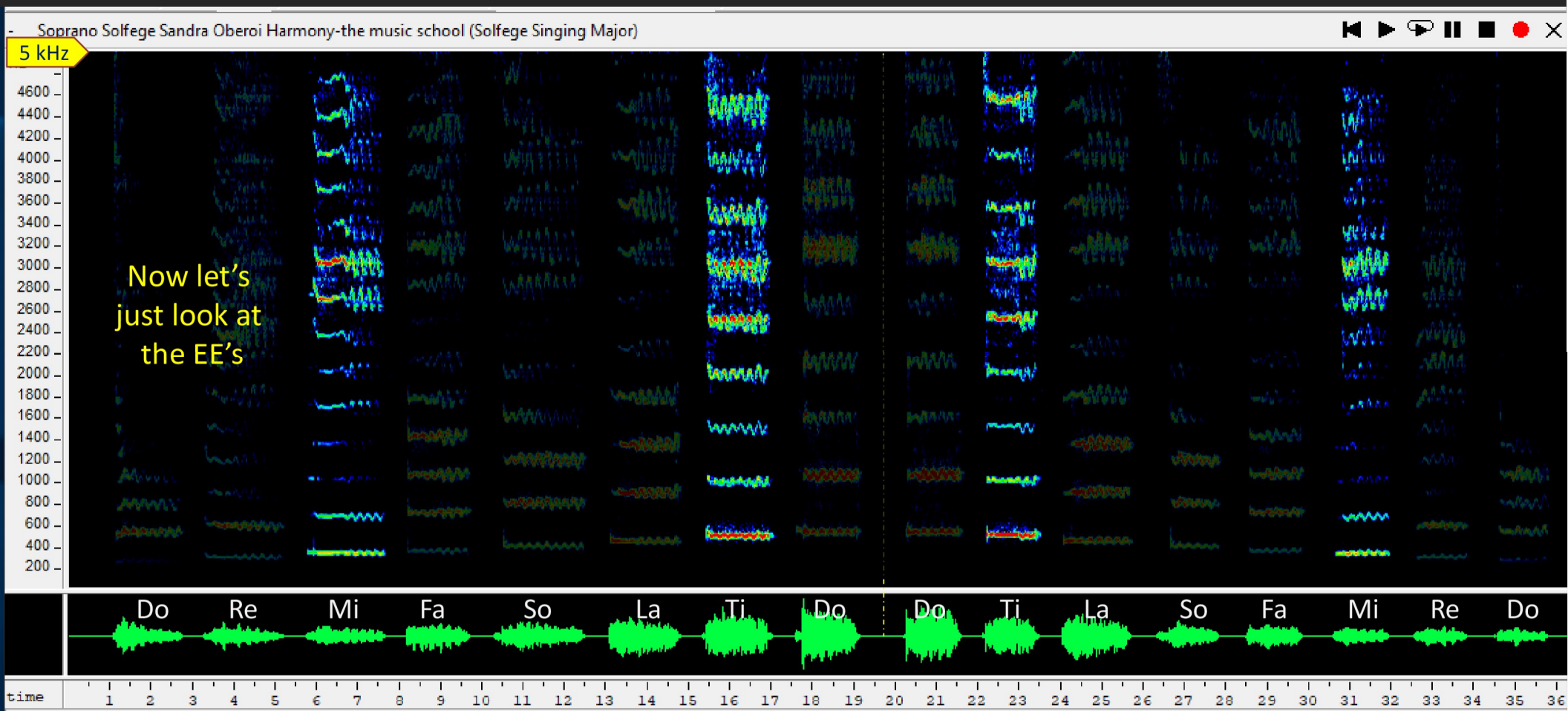


# Solfege: Diatonic C Major Scale [ C4 to C5 ]

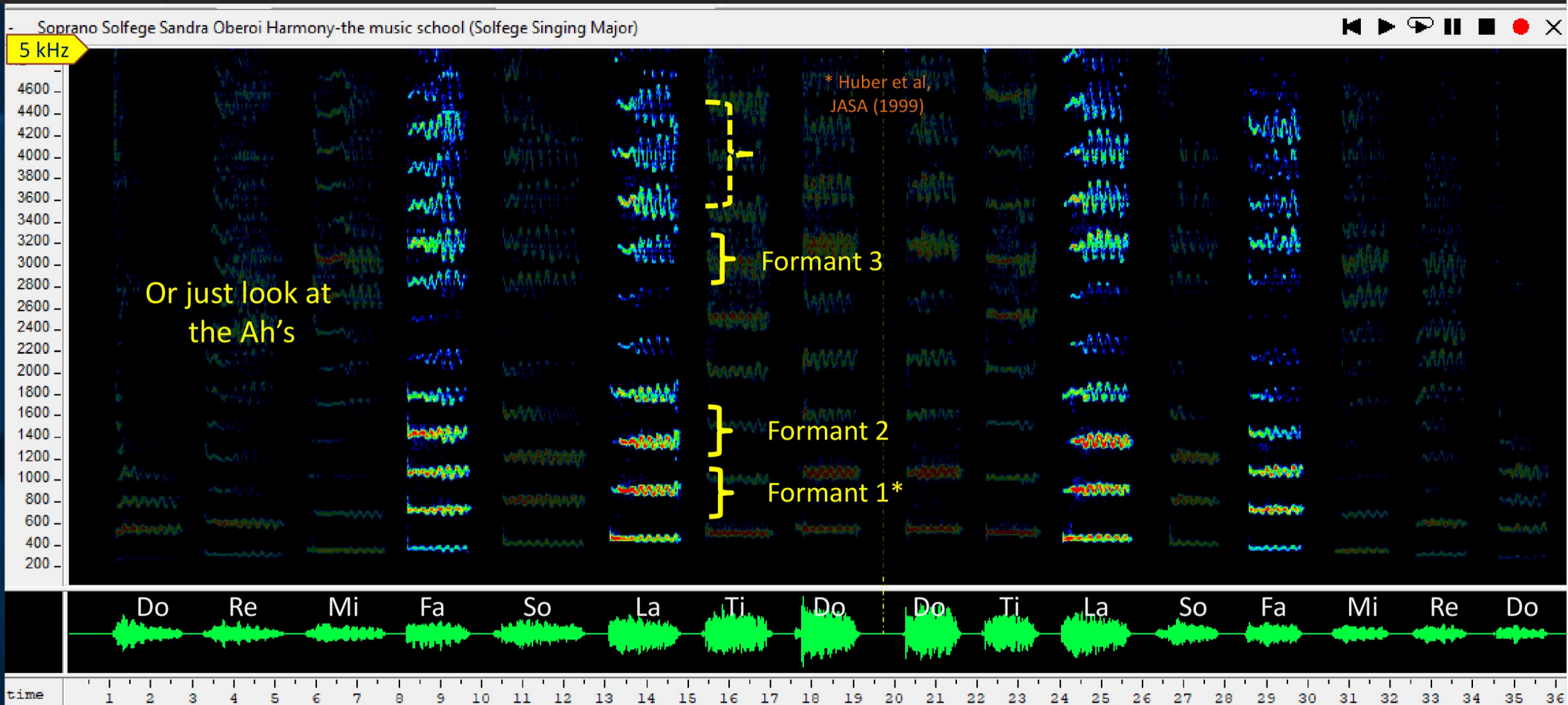




# Solfege: Diatonic C Major Scale [ C4 to C5 ]

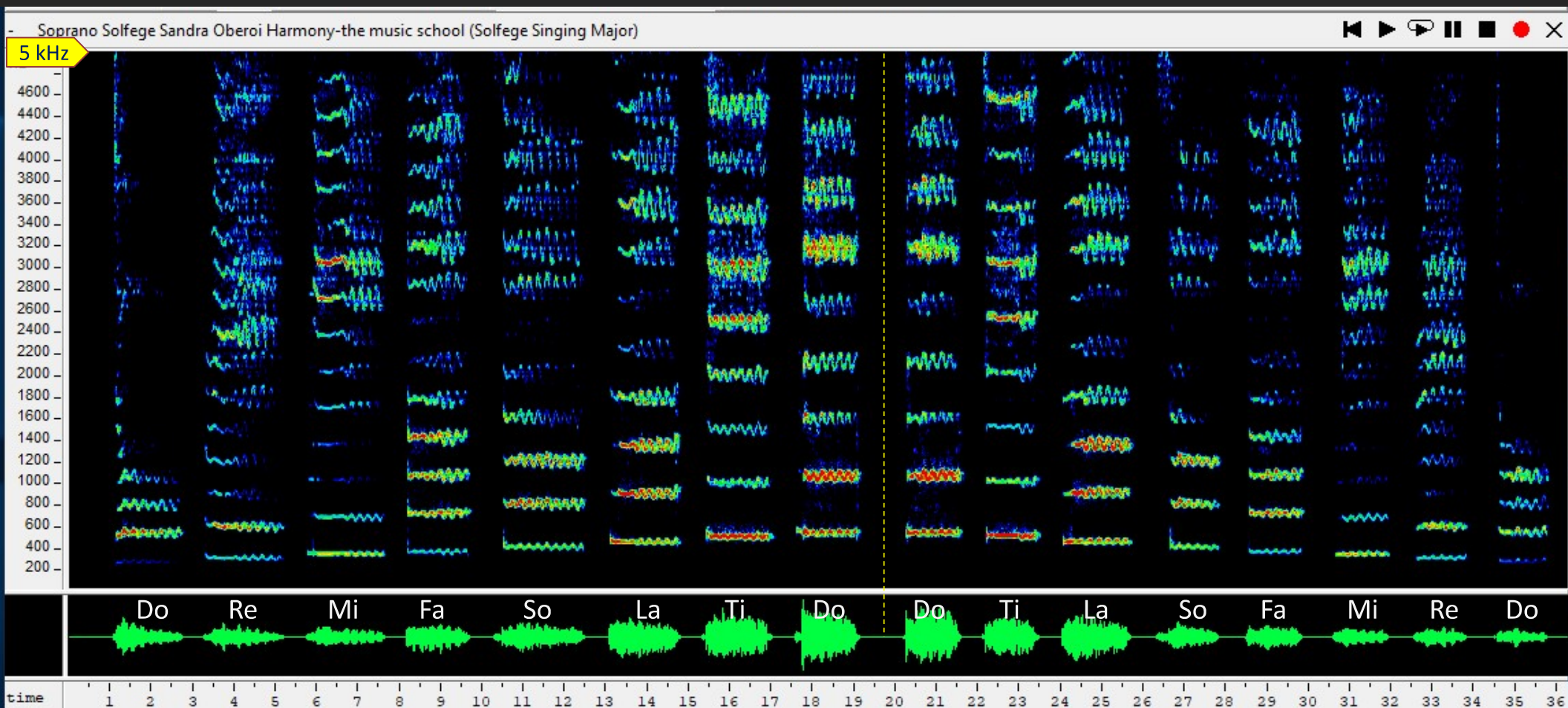


# Solfege: Diatonic C Major Scale [ C4 to C5 ]





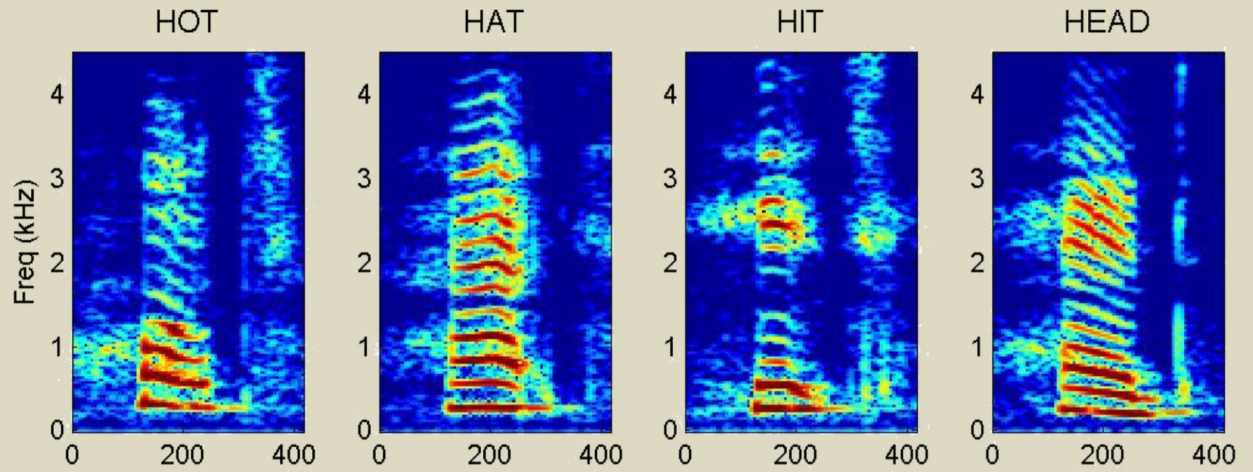
# Solfege: Diatonic C Major Scale [ C4 to C5 ]



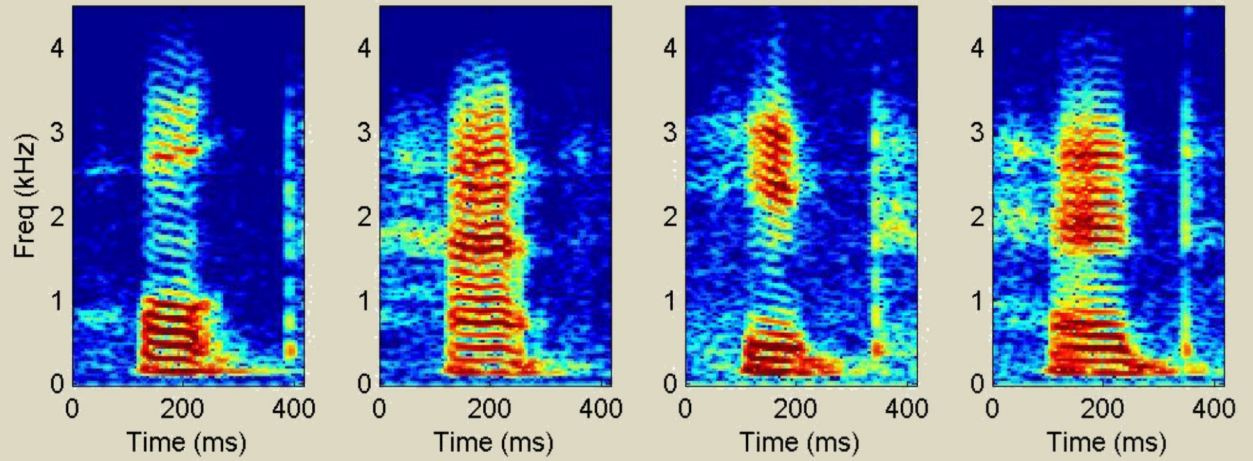


# Vowels with Male and Female Voices

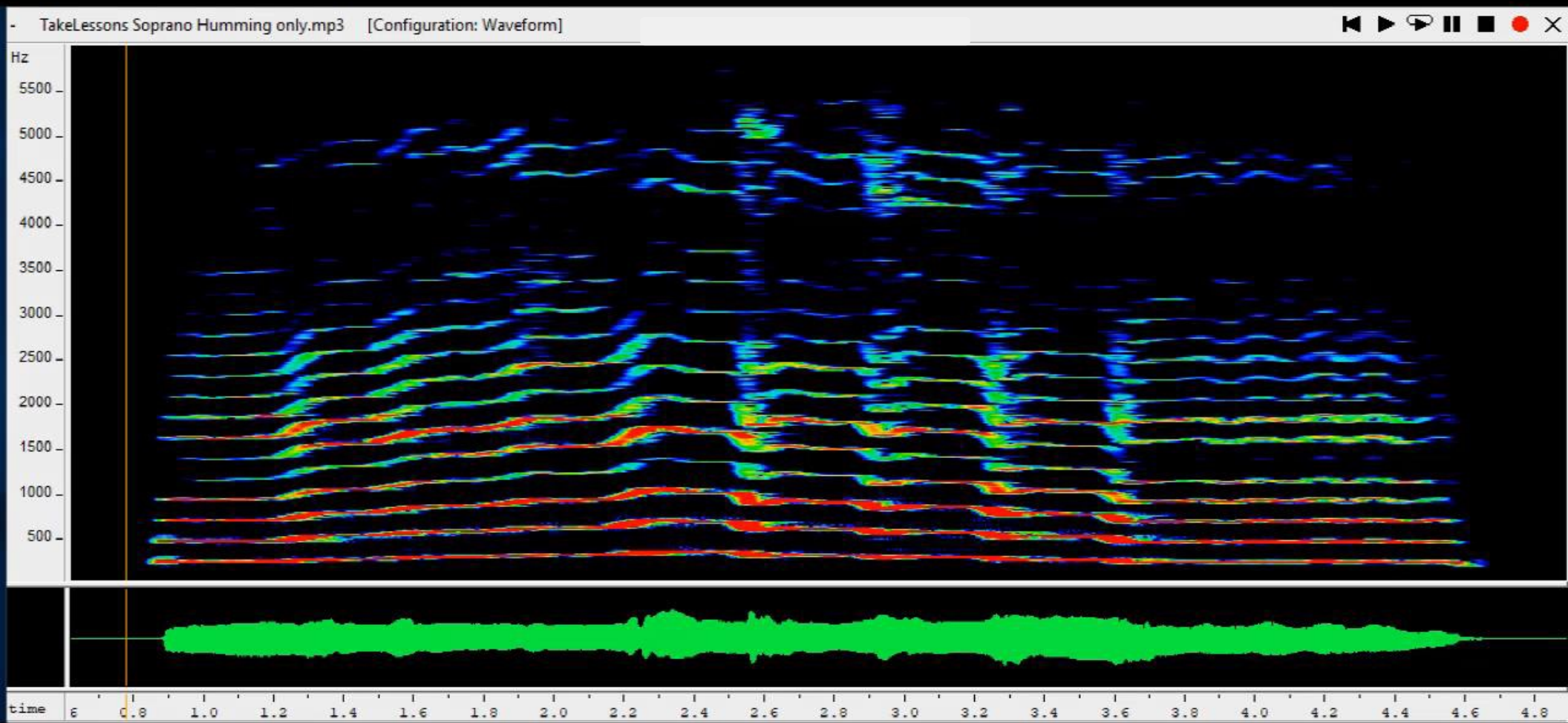
Female



Male



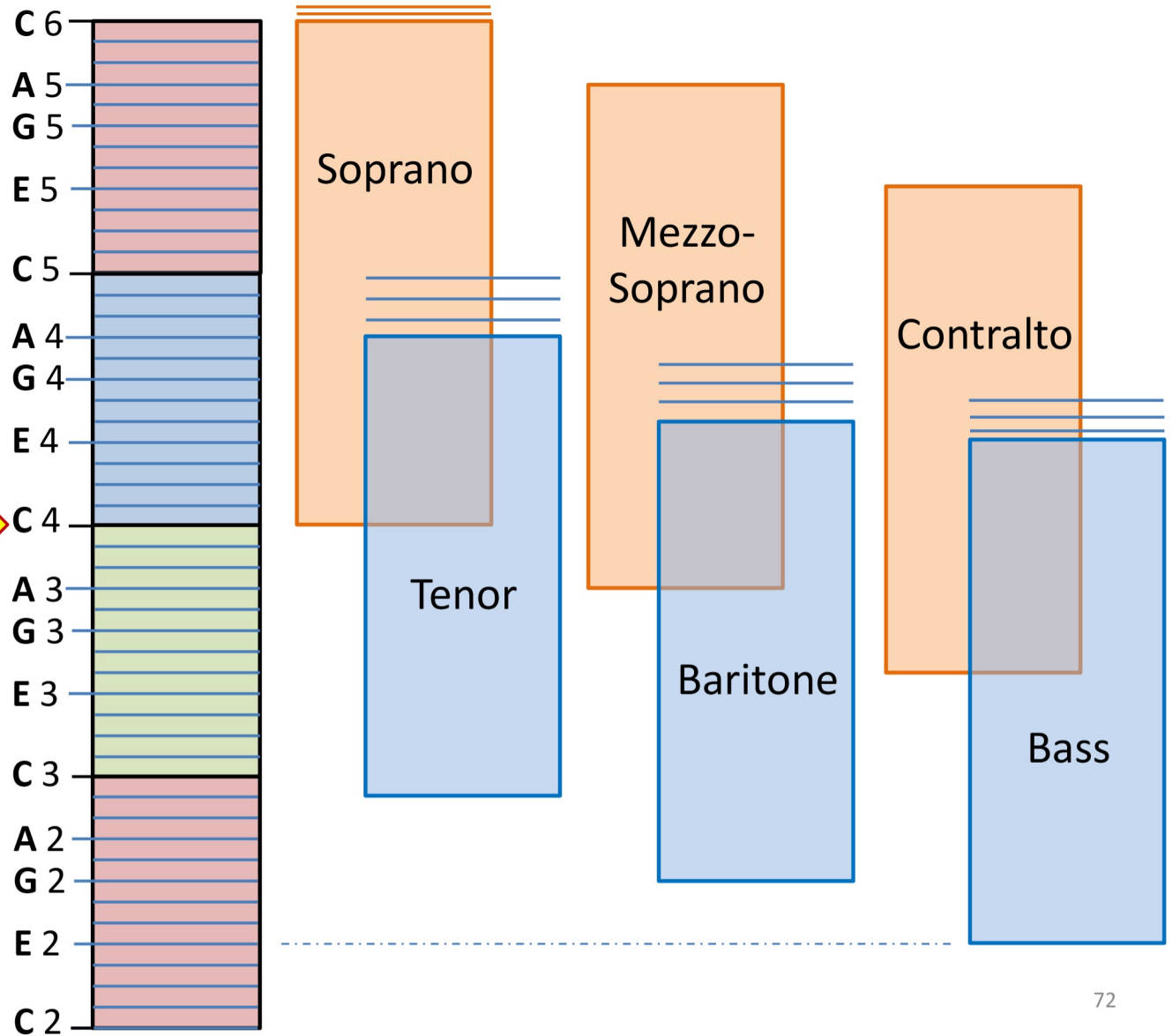
# Female Voice Humming



# Vocal Ranges

- **Soprano**: the highest female voice, being able to sing  $C_4$  to  $C_6$ , and possibly higher.
- **Mezzo-soprano**: a female voice between  $A_3$  and  $A_5$ .
- **Contralto**: the lowest female voice,  $F_3$  to  $E_5$ . Rare contraltos possess a range similar to the tenor.
- **Tenor**: the highest male voice,  $B_2$  to  $A_4$ , and possibly higher.
- **Baritone**: a male voice,  $G_2$  to  $F_4$ .
- **Bass**: the lowest male voice,  $E_2$  to  $E_4$ .

Middle C  
262 Hz





## Question Time

- Singing



- Zoomland
- In Person



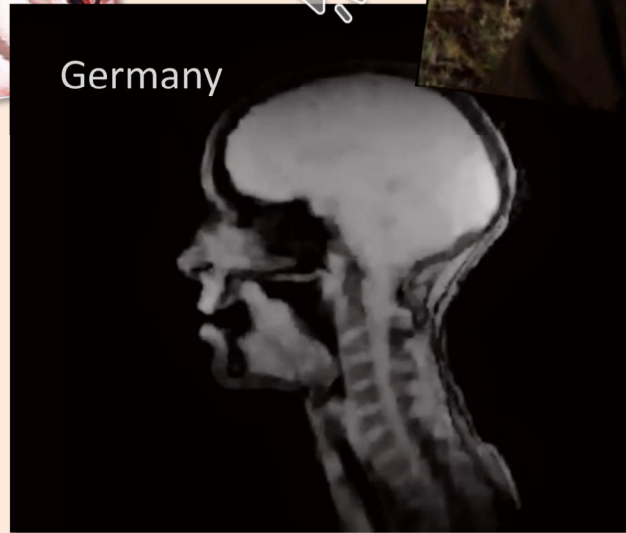
# Throat Singing *a.k.a.* Overtone Singing



Canadian Arctic



Tuva & Mongolia



# Overtone Singing Example

- Anna-Maria Hefele
- Music Video 2017
  - Regular singing
  - Harp
  - Overtone singing
- Song:  
*By This River* (Brian Eno)
- MRI Sequences:
  - Prof. Bernhard Richter et. al.  
Freiburg Institute for Musician's Medicine  
(University of Music Freiburg)





Overtone  
Singing



Anna-Maria  
Hefele 2017



# Overtone Singing



Anna-Maria  
Hefele 2017



# Anna-Marie Hefele overtone singing

