OSHER LIFELONG LEARNING INSTITUTE

An Ear for Music

Plainsong and Gregorian Chants
Hymn *Lucis Creator* and a Canticle
Beauty in Sound (2019)

Session 8
Harmony and Dissonance

OLLI at Illinois

Spring 2024

D. H. Tracy

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. **Chords; Harmony and Dissonance**

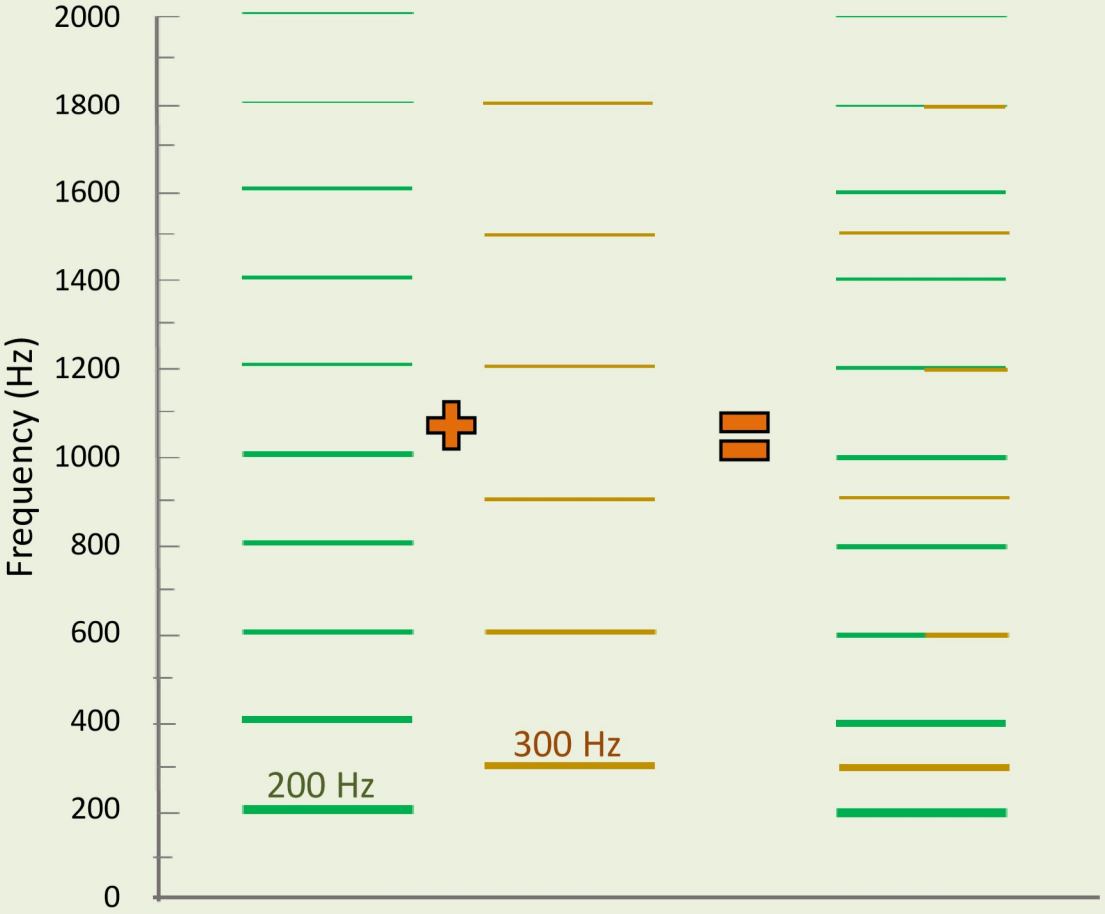
Chords

- 2 or more notes played simultaneously
  - Commonly 3 or 4 *(Triads or Tetrads)*
  - *Normally* chosen to sound good together
- Require musical instrument capable of simultaneous notes
  - e.g. Piano, Organ, Guitar, Harp
  - NOT Singing Voice, Bowed Strings, Woodwinds, Brasses etc.

OR Multiple Instruments or Singers

- Much more common in Western music than in other traditions
- Frequently occur in sequences called **Progressions**

The Power Chord



- Combination of 2 notes played together
- **3:2** Frequency Ratio
- Also called “Fifth Chord” or “Open Fifth”

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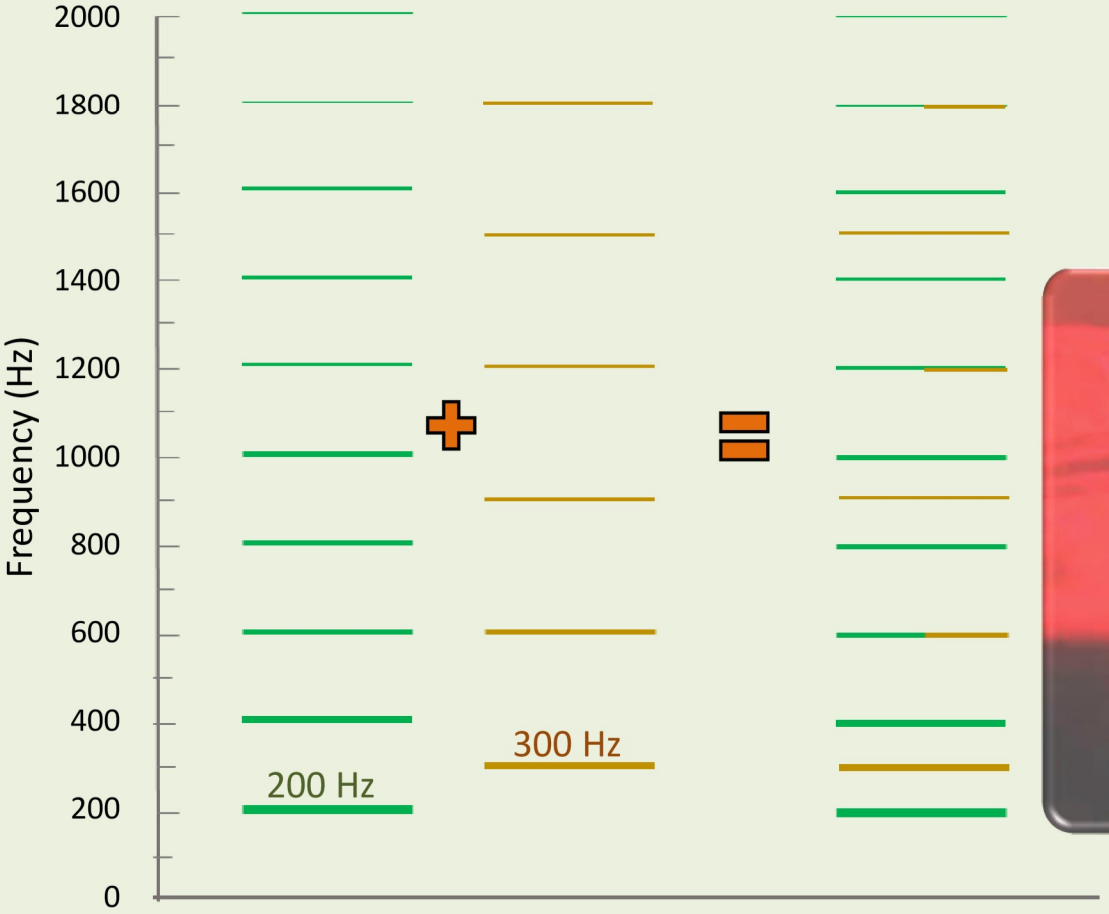

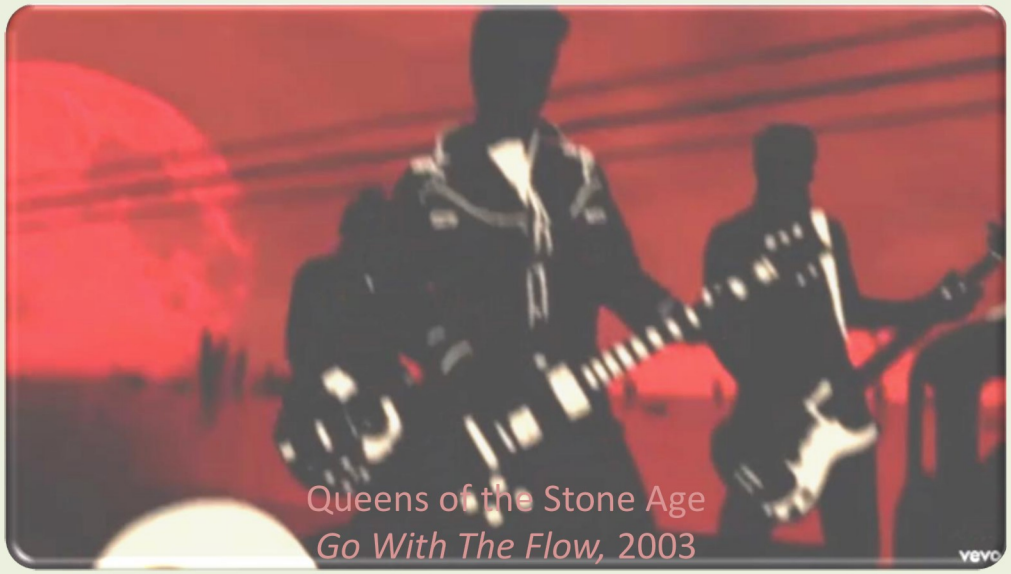

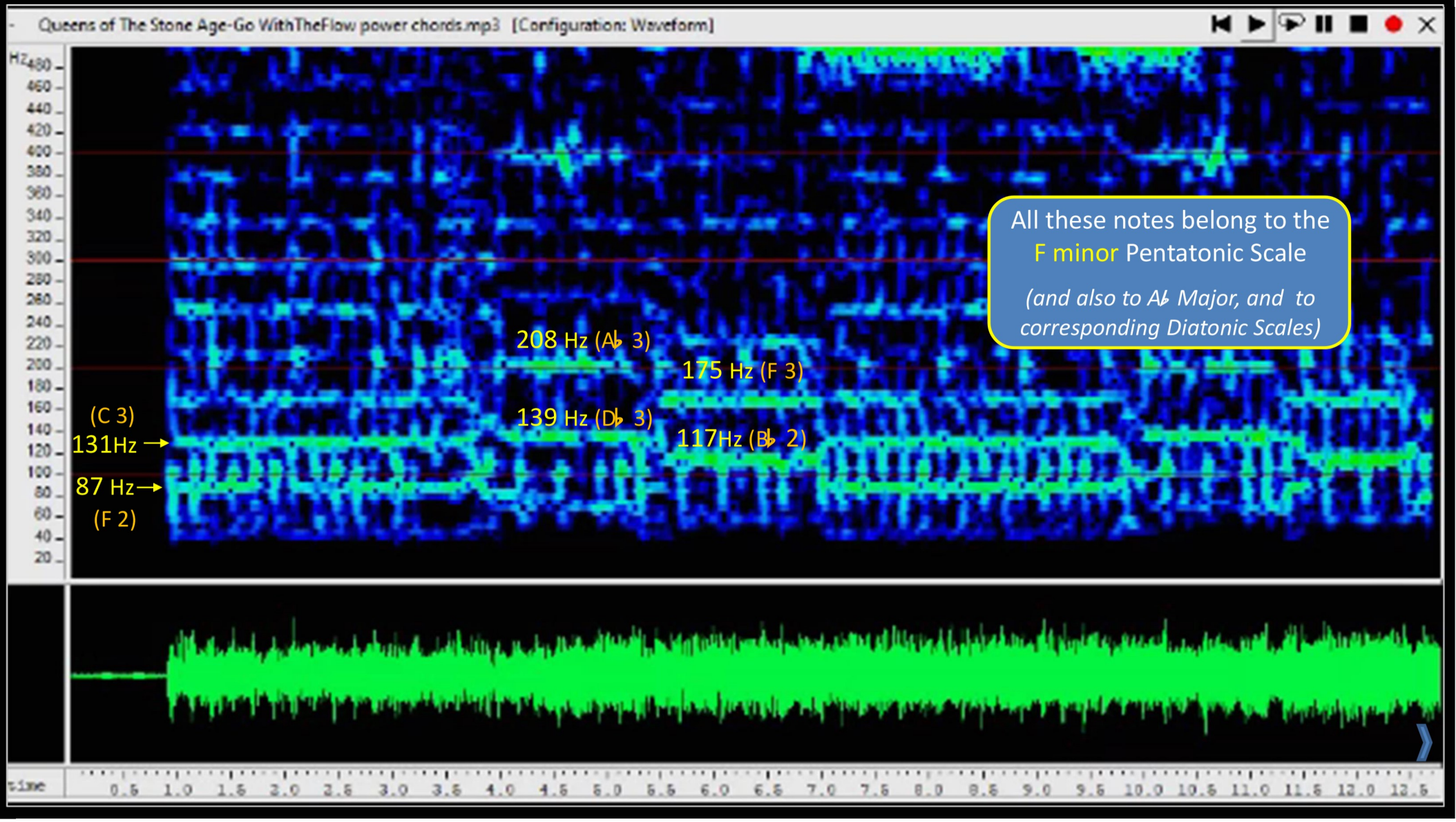
Queens of The Stone Age-Go WithTheFlow power chords.mp3 [Configuration: Waveform]
Hz
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
All these notes belong to the F minor Pentatonic Scale
(and also to A♭ Major, and to corresponding Diatonic Scales)
208 Hz (A♭ 3)
175 Hz (F 3)
139 Hz (D♭ 3)
117Hz (B♭ 2)
(C 3)
131Hz
87 Hz
(F 2)
time
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 10.5 11.0 11.5 12.0 12.5

The Power Chord

"Fifth Chord"

- Combination of 2 notes played together
- **3:2** Frequency Ratio
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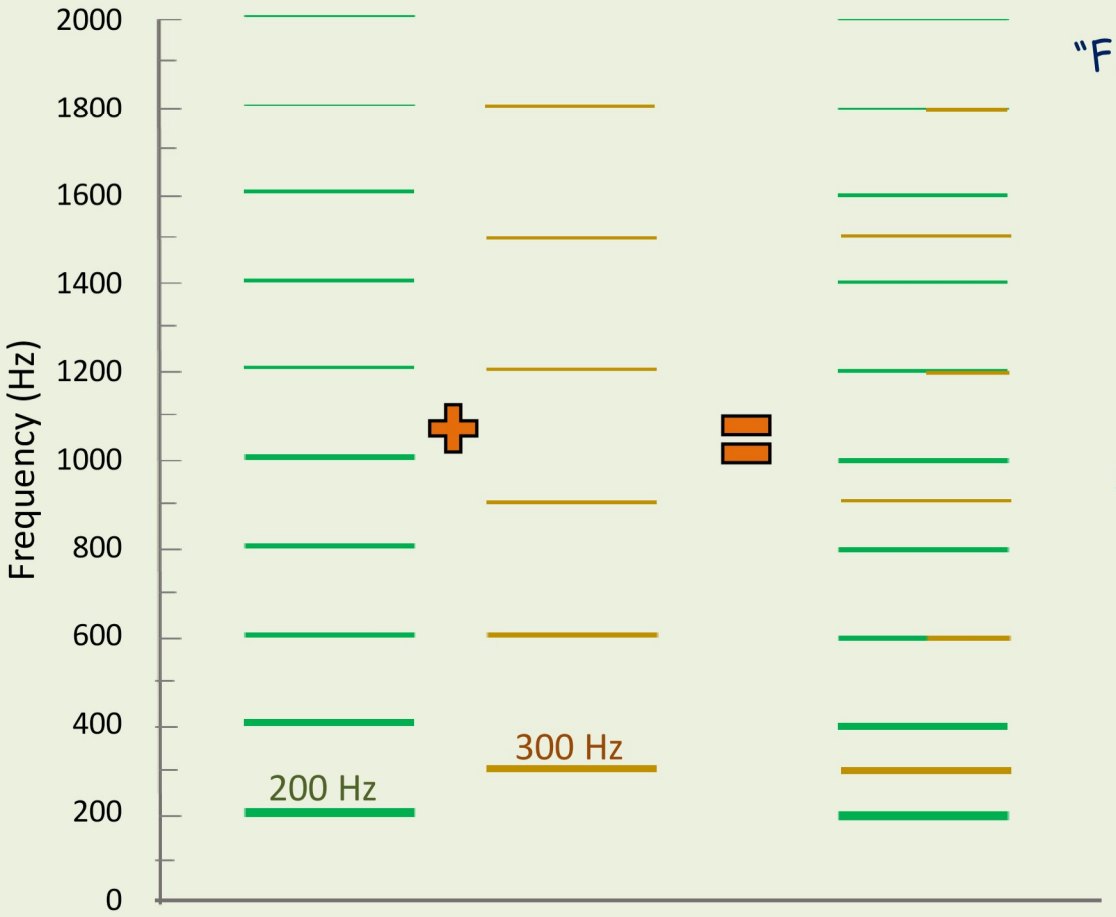
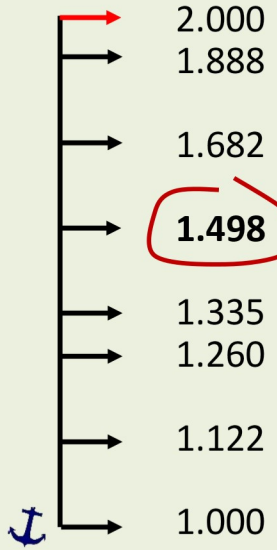


The dirty little secret:
In the scales we have studied so far there *are no* **3:2** frequency ratios!

Example:
Diatonic Major Scale
(Equal Tempered)



Good enough for human ears!

Common Triad Chords

(Based on Diatonic Scales)

Note	MIDI	f
C#/D♭ 6	85	1108.7
C 6	84	1046.5
B 5	83	987.8
A#/B♭ 5	82	932.3
A 5	81	880
G#/A♭ 5	80	830.6
G 5	79	784.0
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F 5	77	698.5
E 5	76	659.3
D#/E♭ 5	75	622.3
D 5	74	587.3
C#/D♭ 5	73	554.4
C 5	72	523.3
B 4	**71**	**493.9**
A#/B♭ 4	**70**	**466.2**
A 4	**69**	**440**
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G 4	**67**	**392.0**
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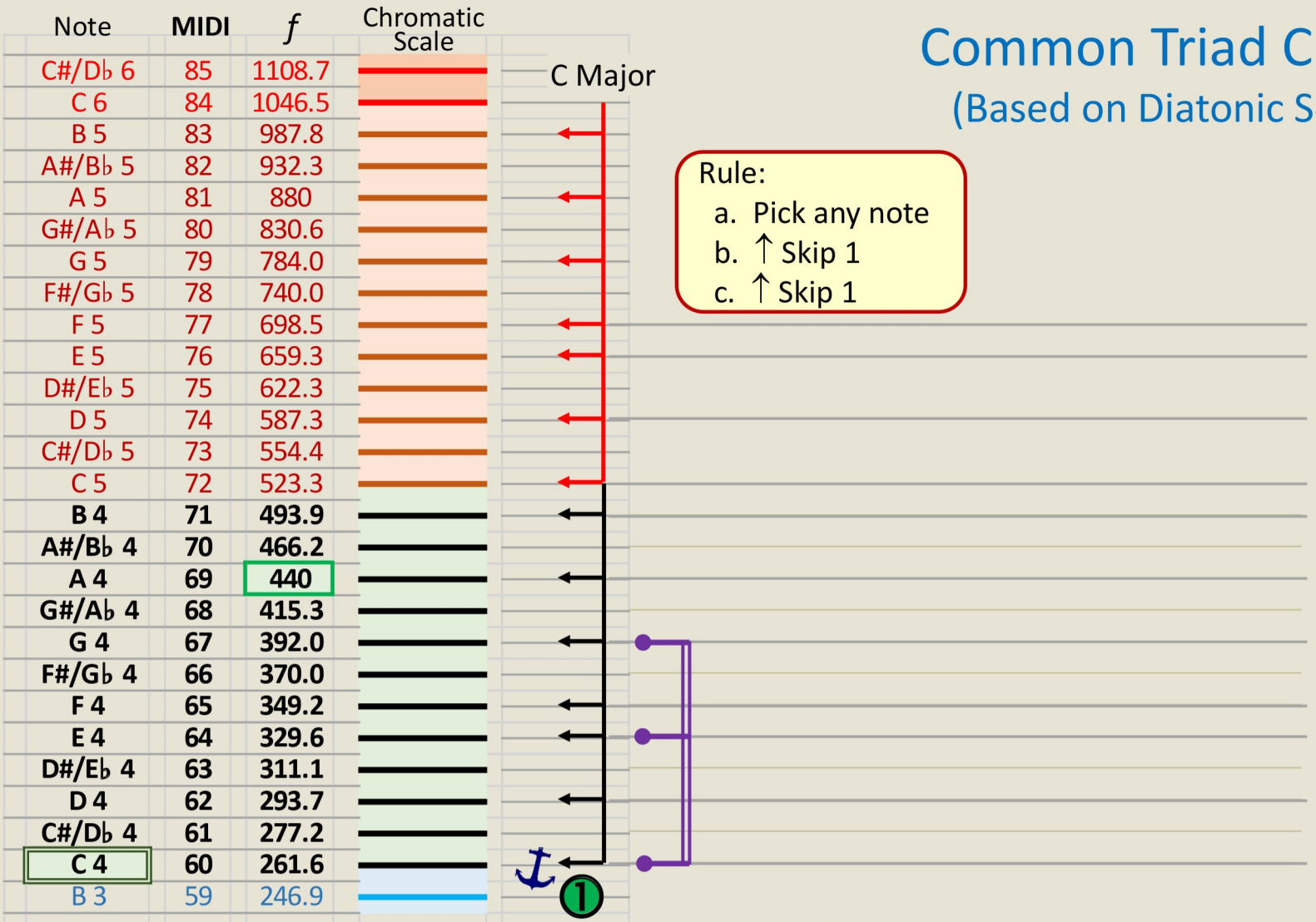
D 4	**62**	**293.7**
C#/D♭ 4	**61**	**277.2**
C 4	**60**	**261.6**
B 3	59	246.9

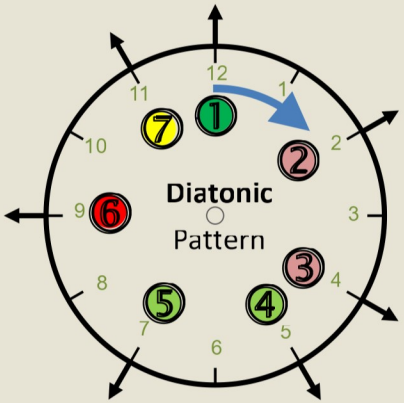


Rule:

a. Pick any note

b. ↑ Skip 1

c. ↑ Skip 1



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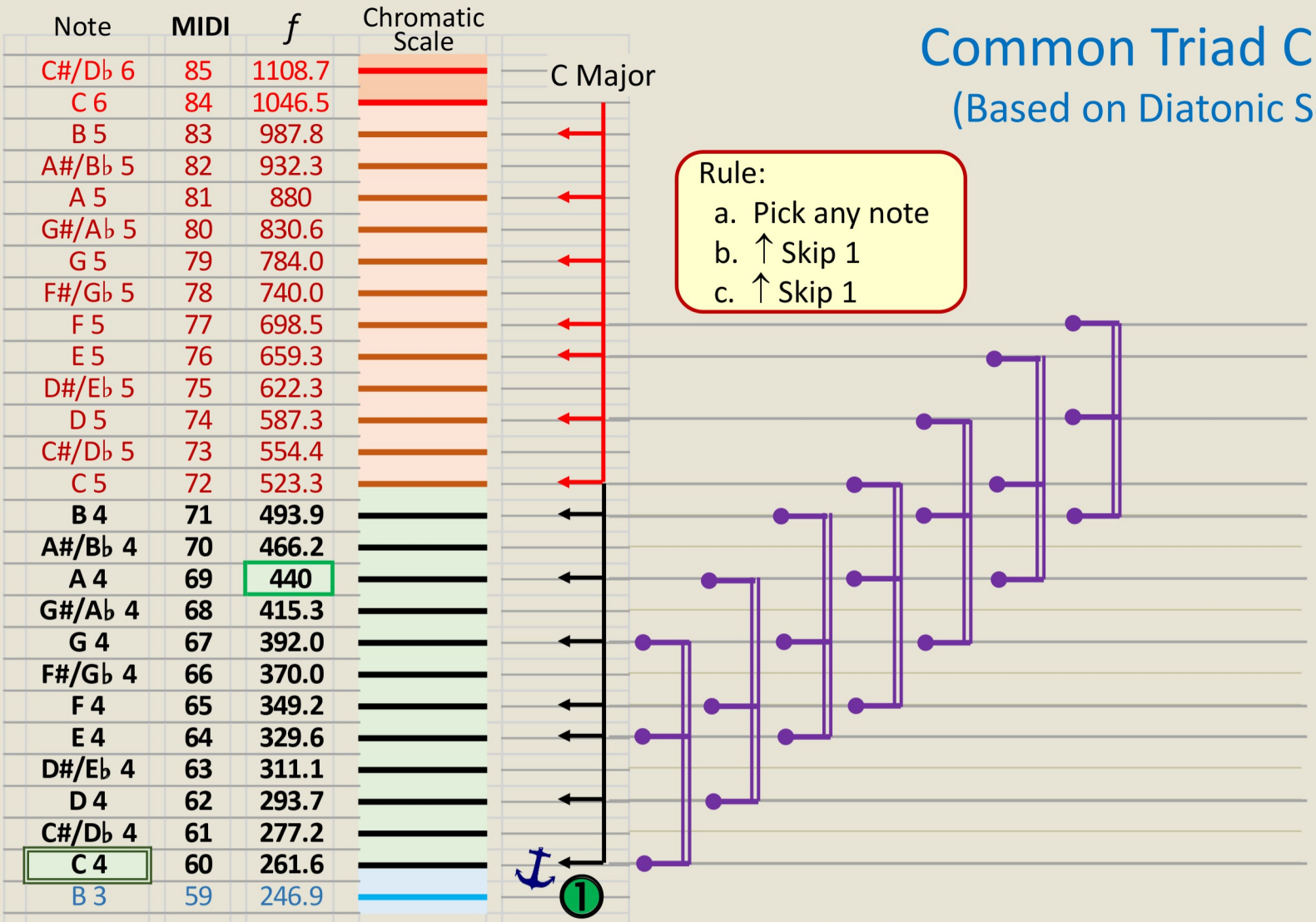

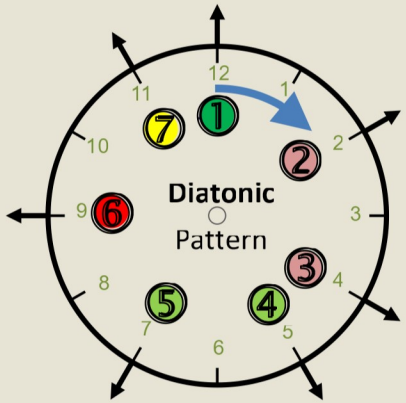

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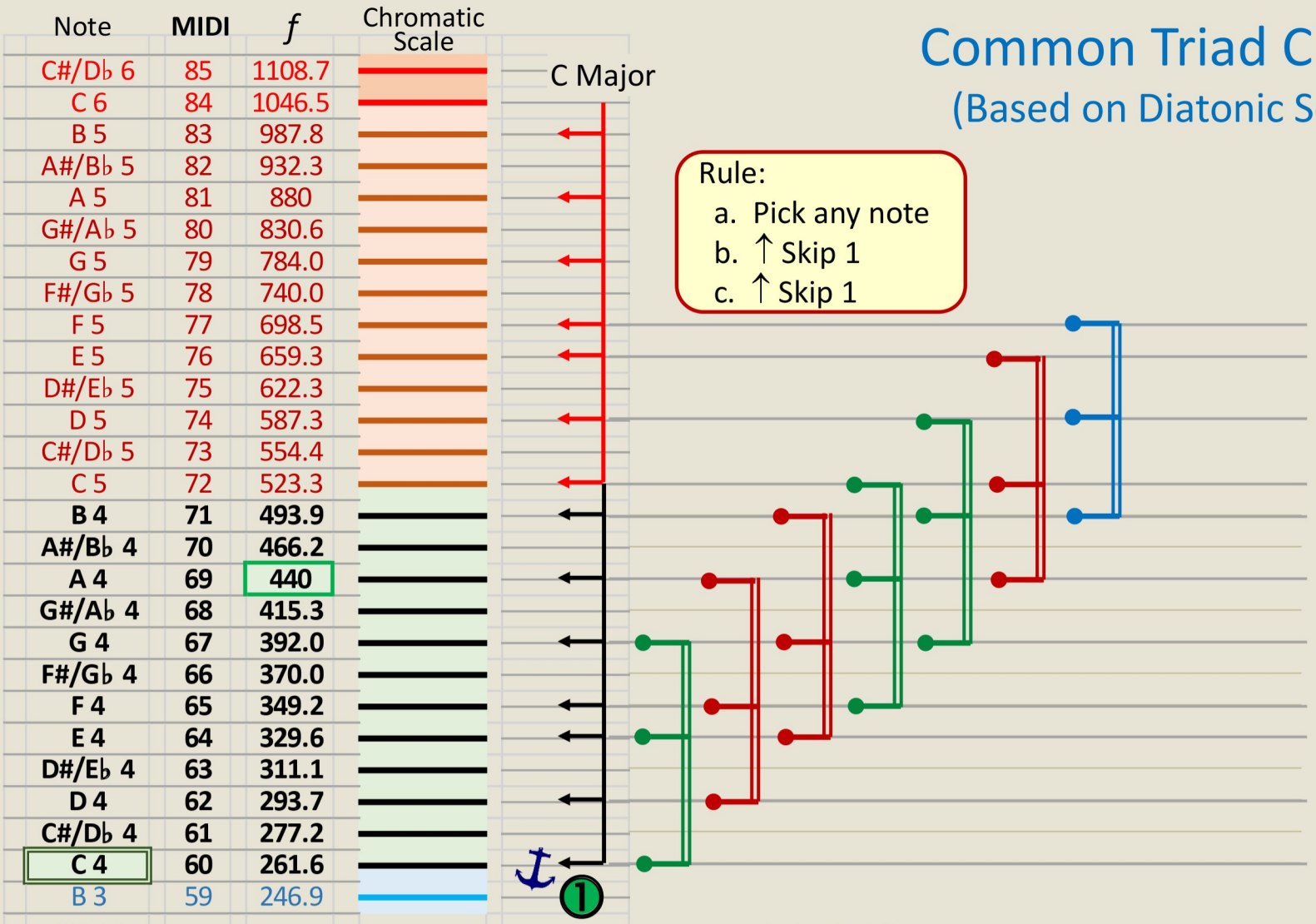

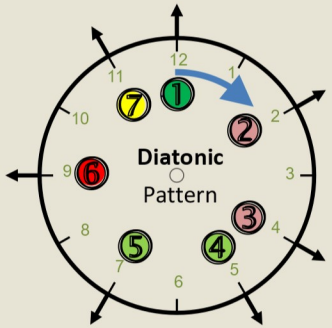

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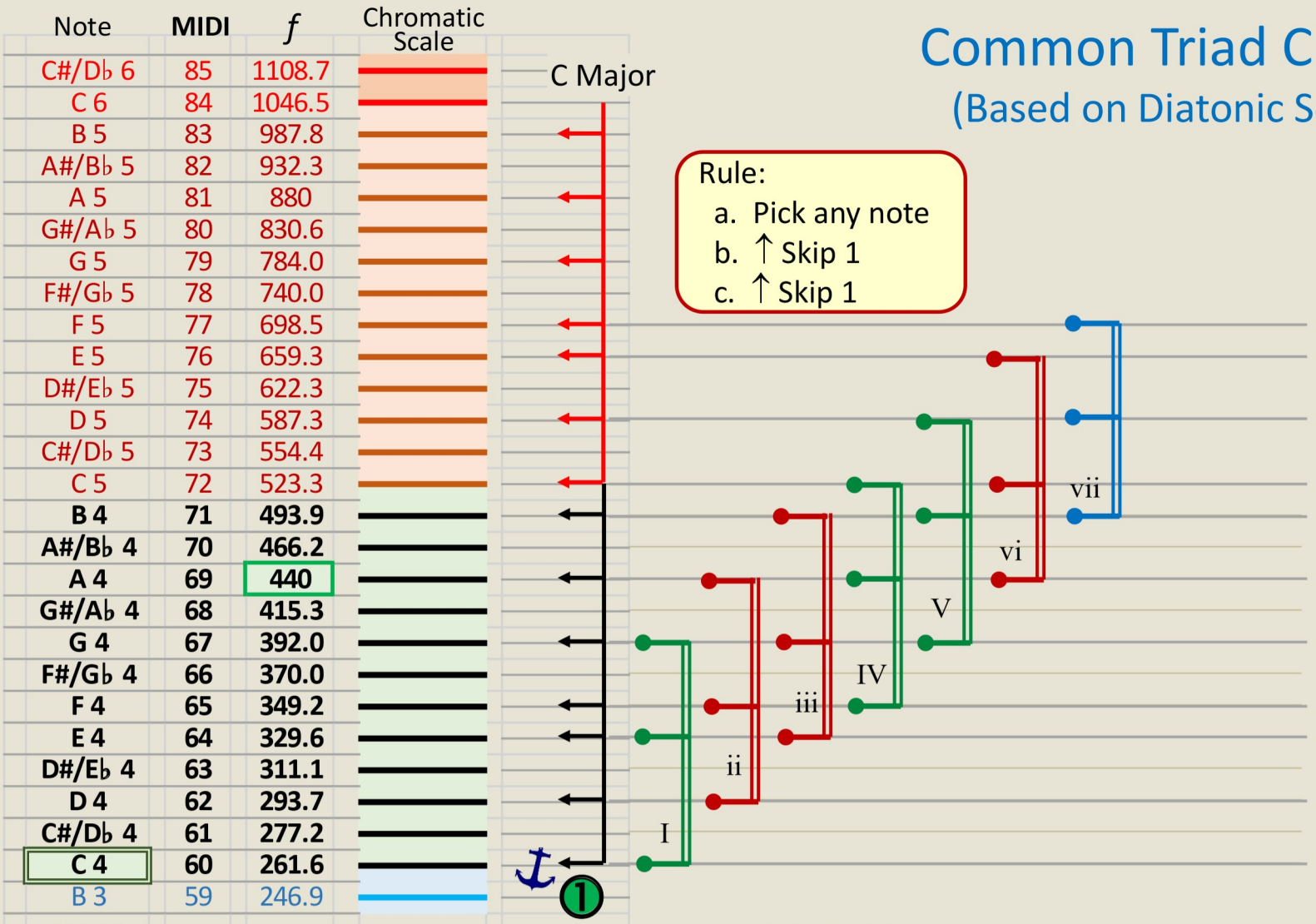

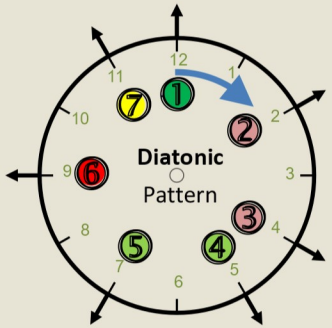

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Chromatic Scale

C Major

Rule:
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Tetrads

I ii iii IV V vi vii

Once Again…

Major: 5:4

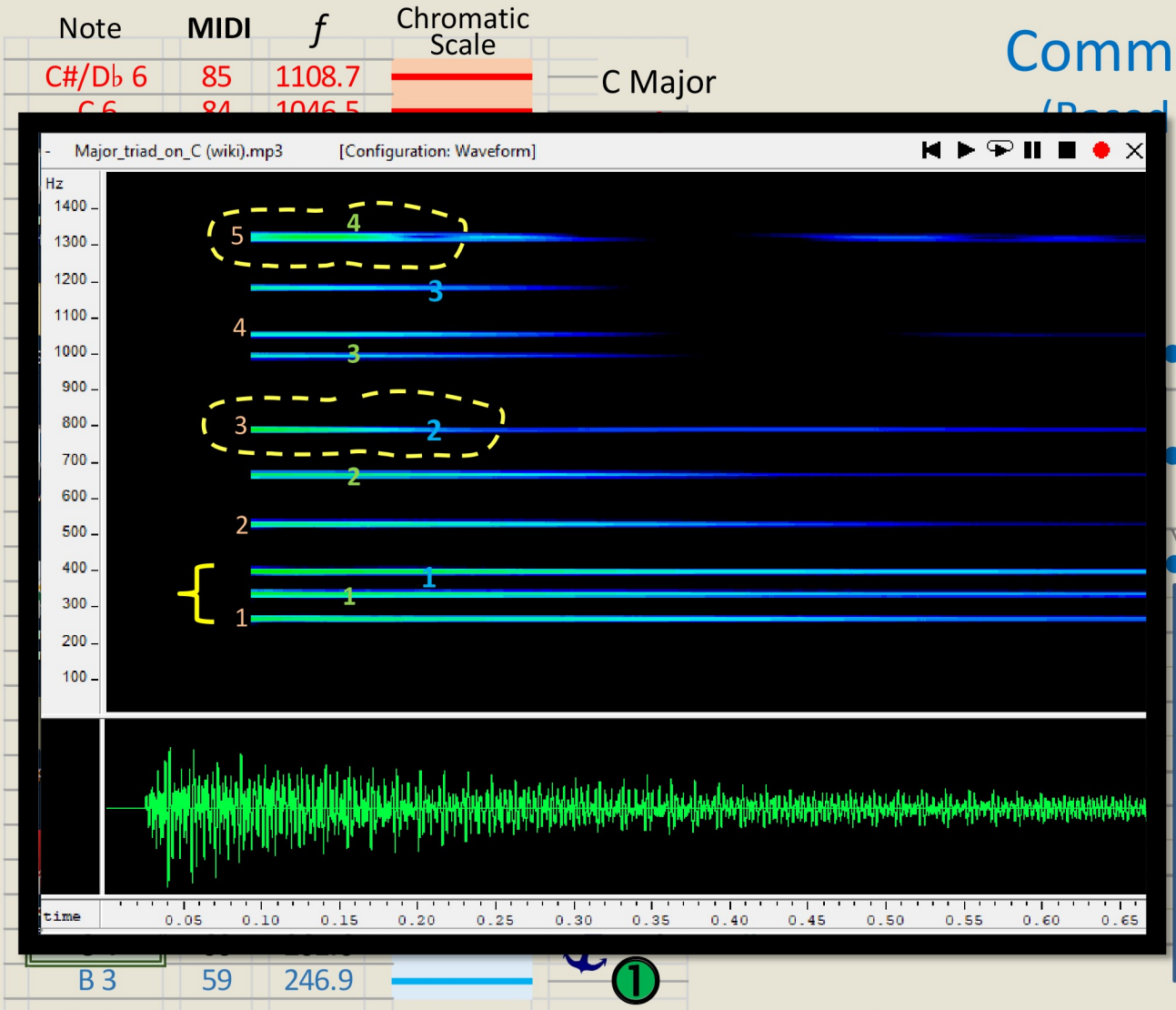
minor: ~6:5

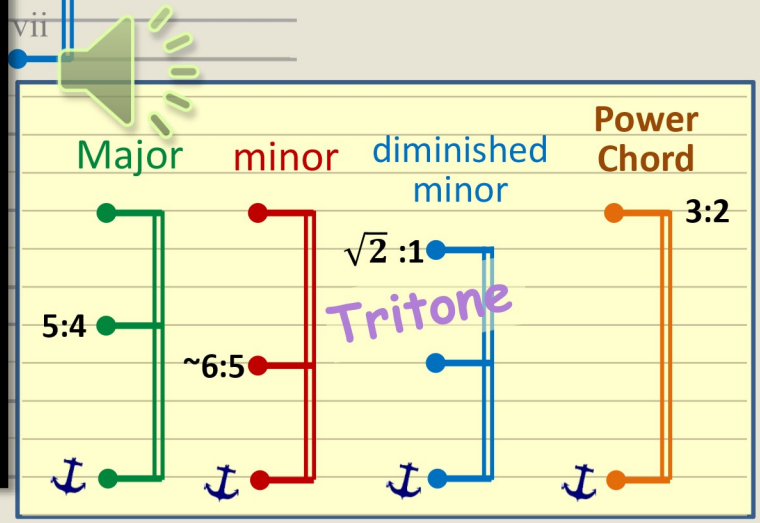
diminished minor: $\sqrt{2}$:1 Tritone

Power Chord: 3:2

Common Triad Chords

(Based on Diatonic Scales)





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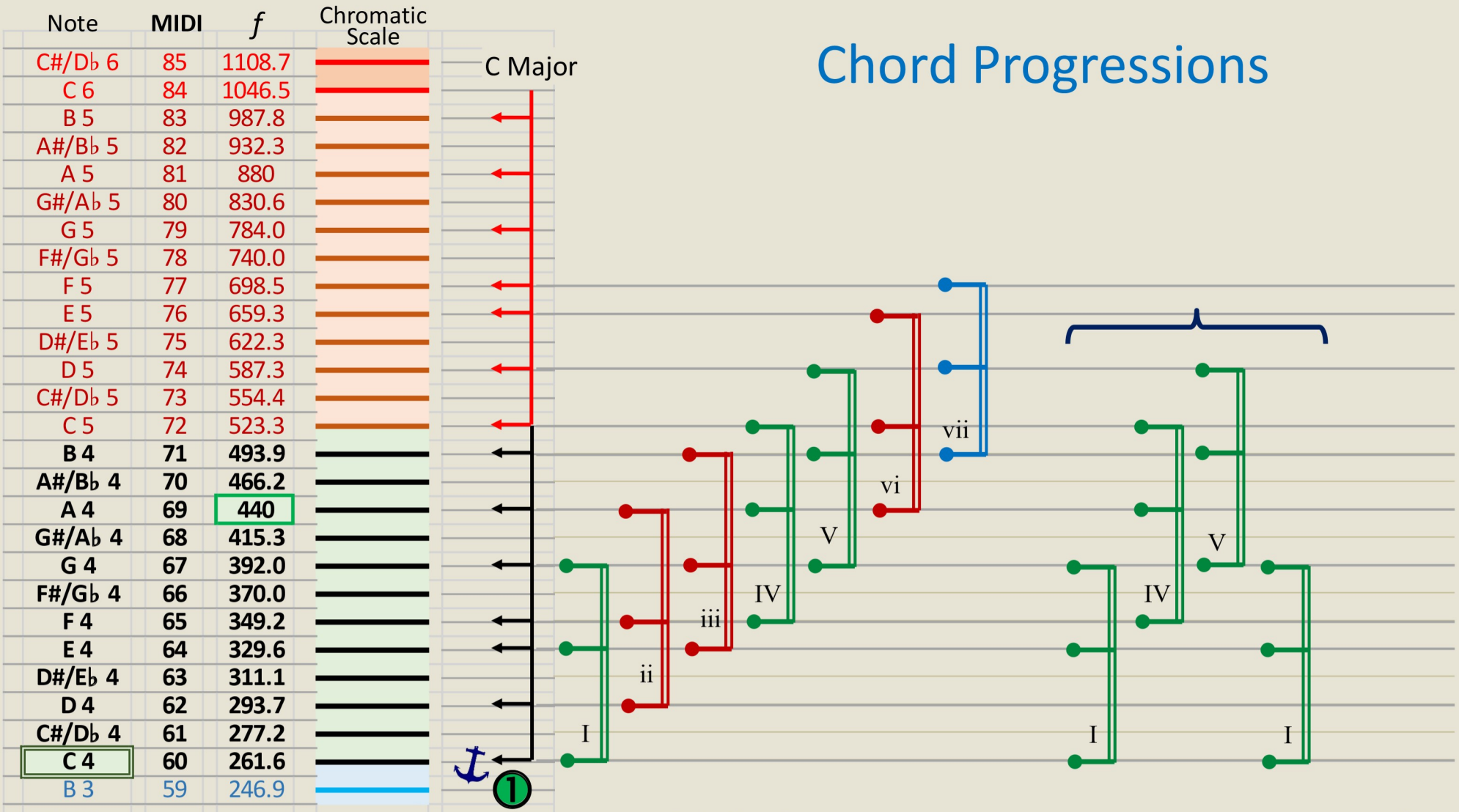

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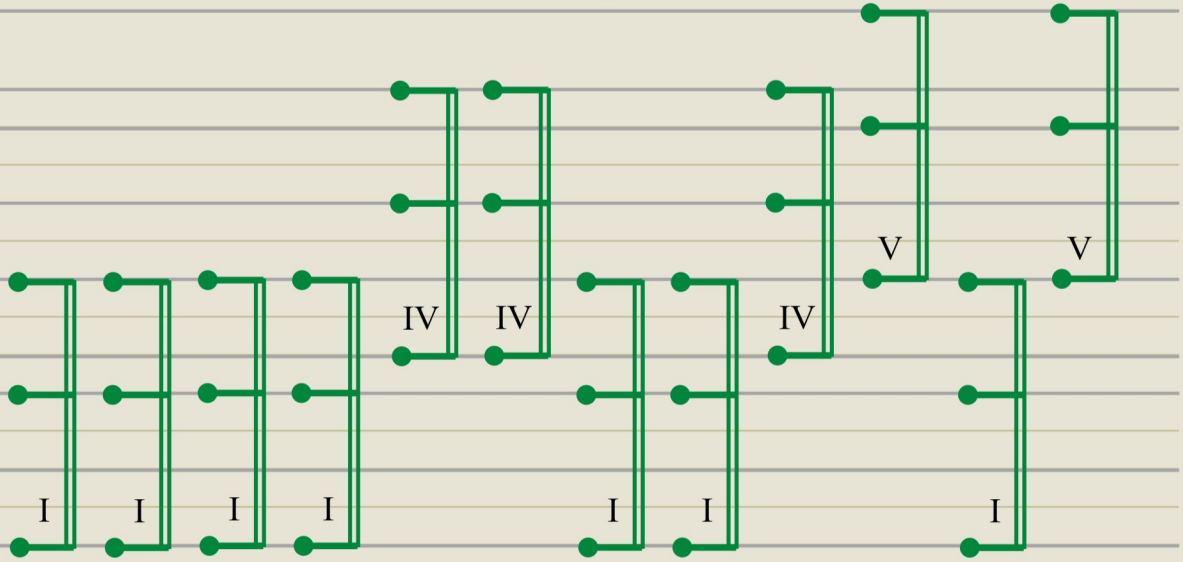
Chromatic Scale

C Major

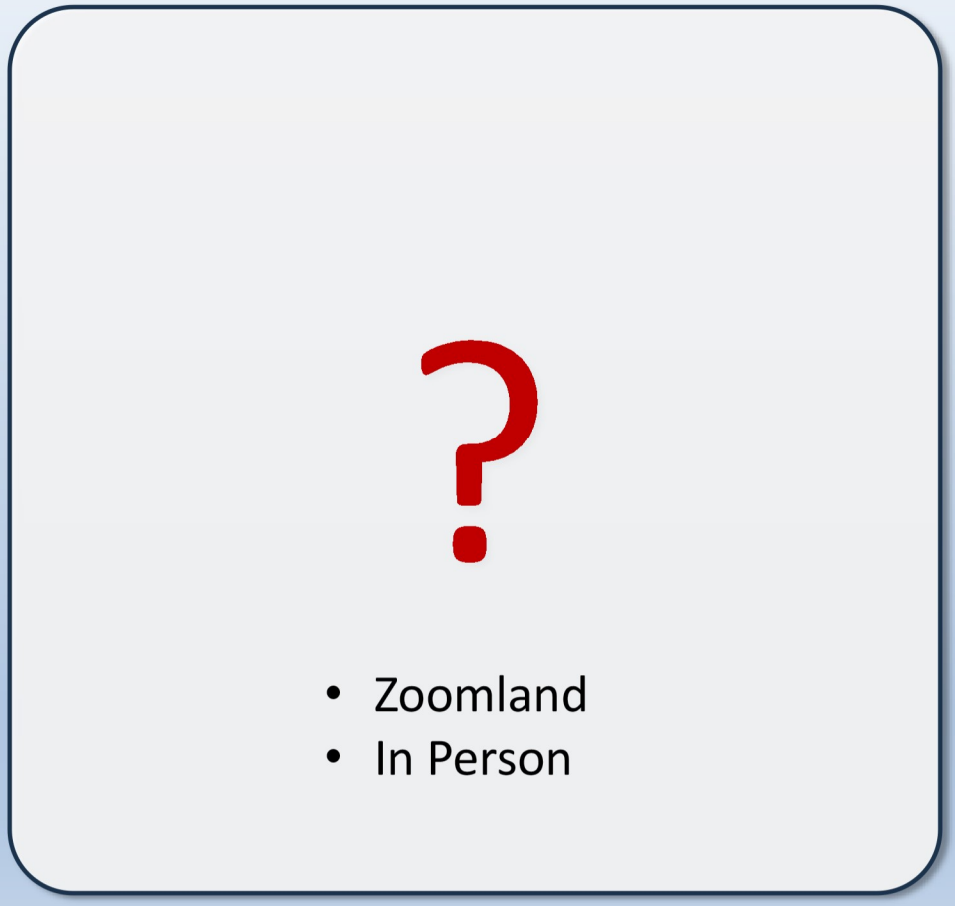
Chord Progressions

The 12 Bar Blues

Boogie Woogie

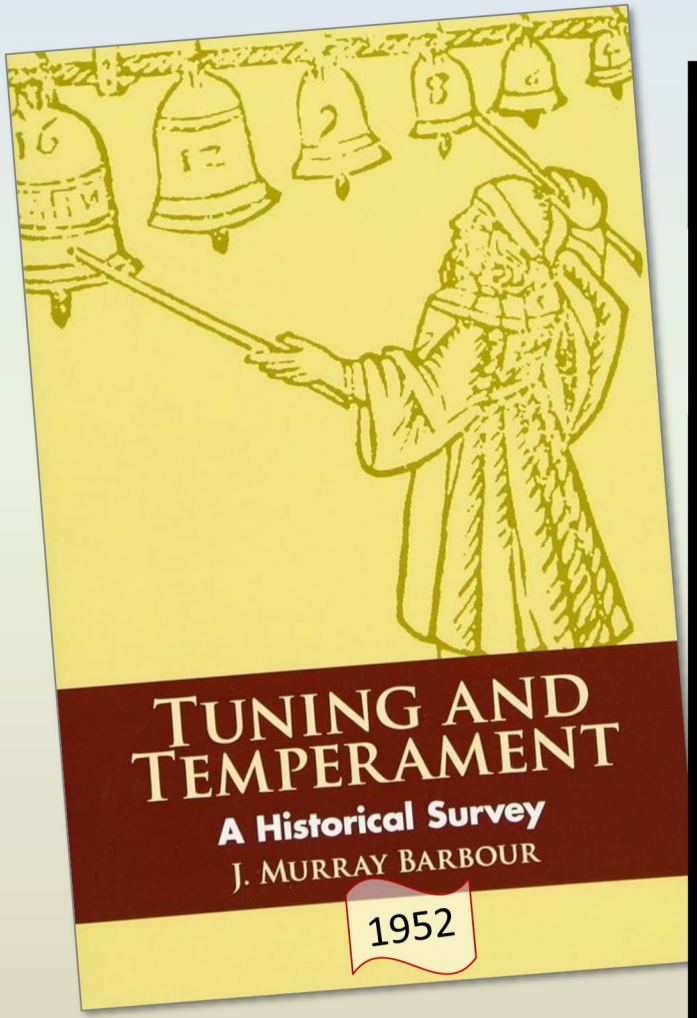


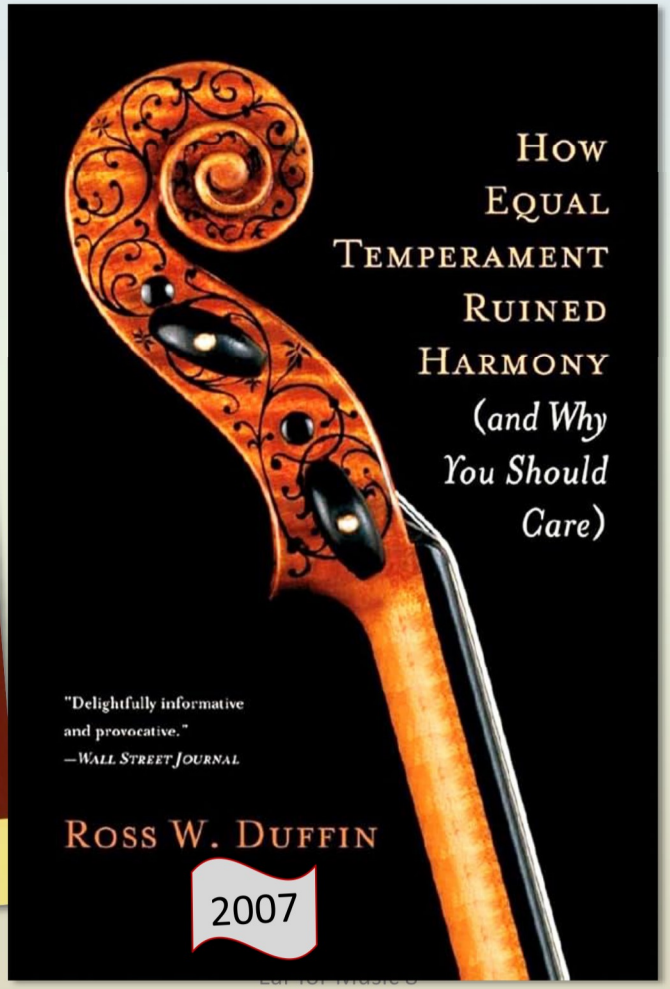
Question Time

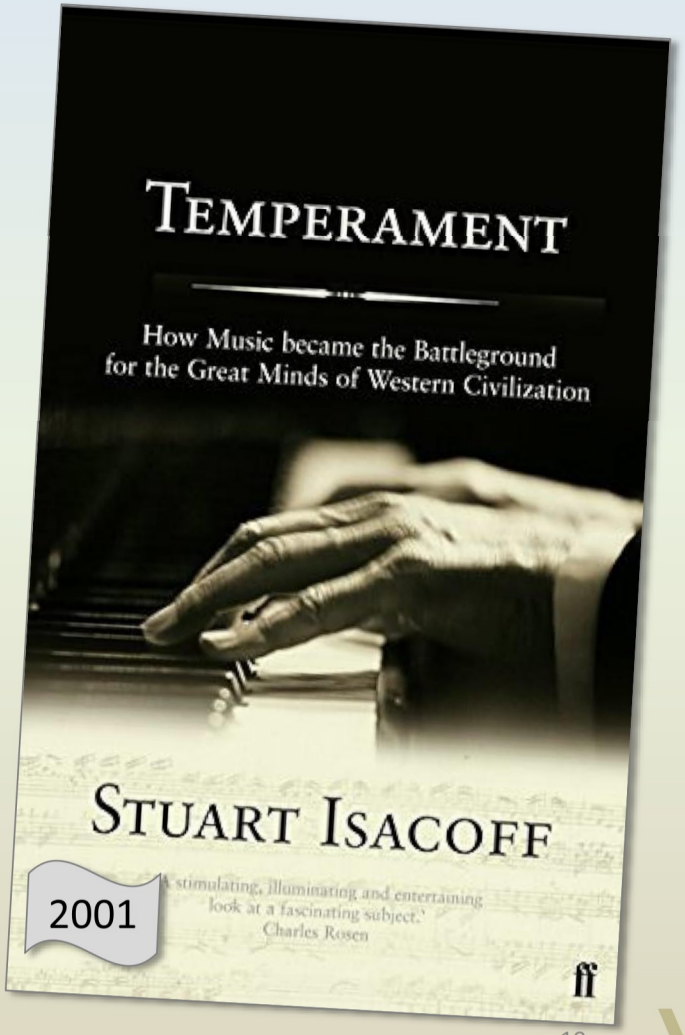


How We Process Music|Neuroscience for Musicians
Danny Li *(YouTube 2022, 14 min)*

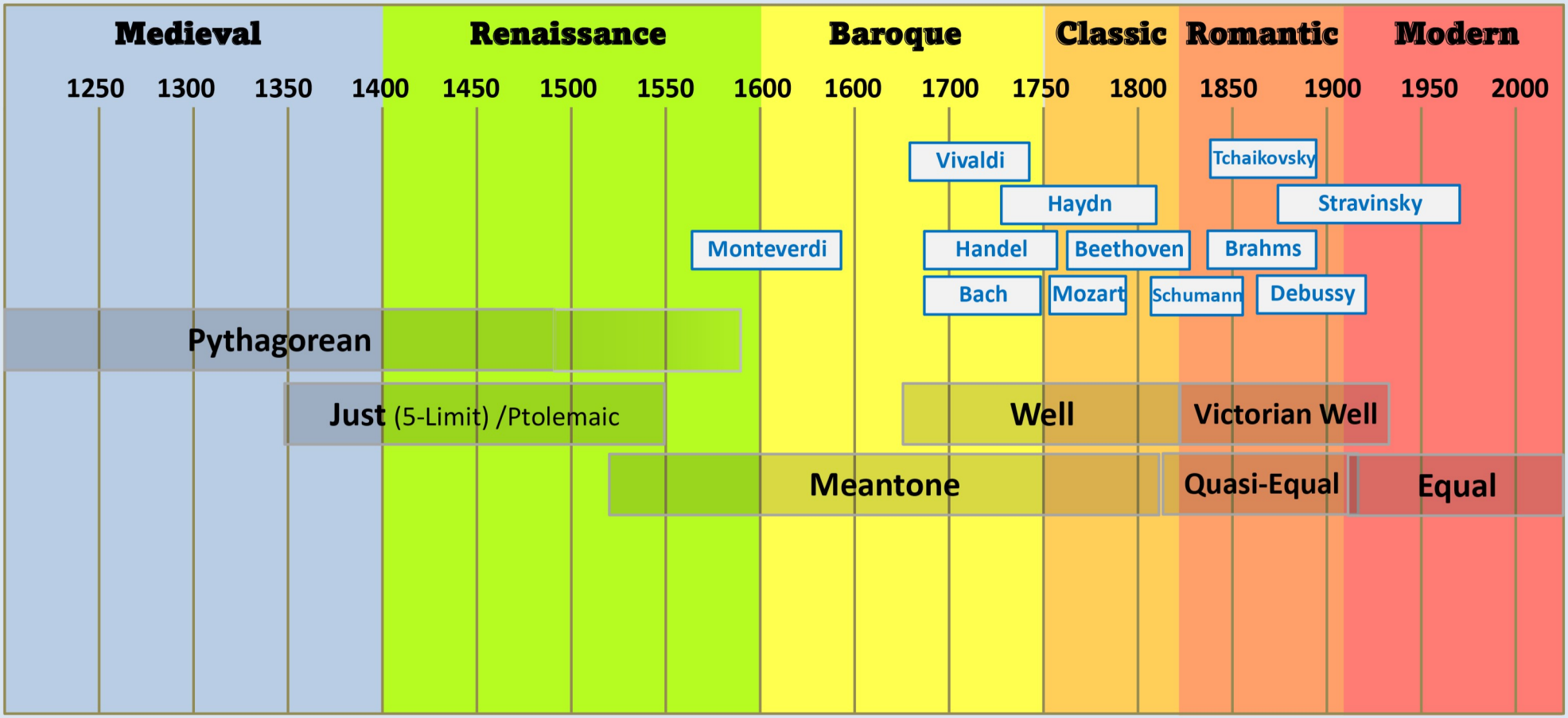
The Temperament Wars



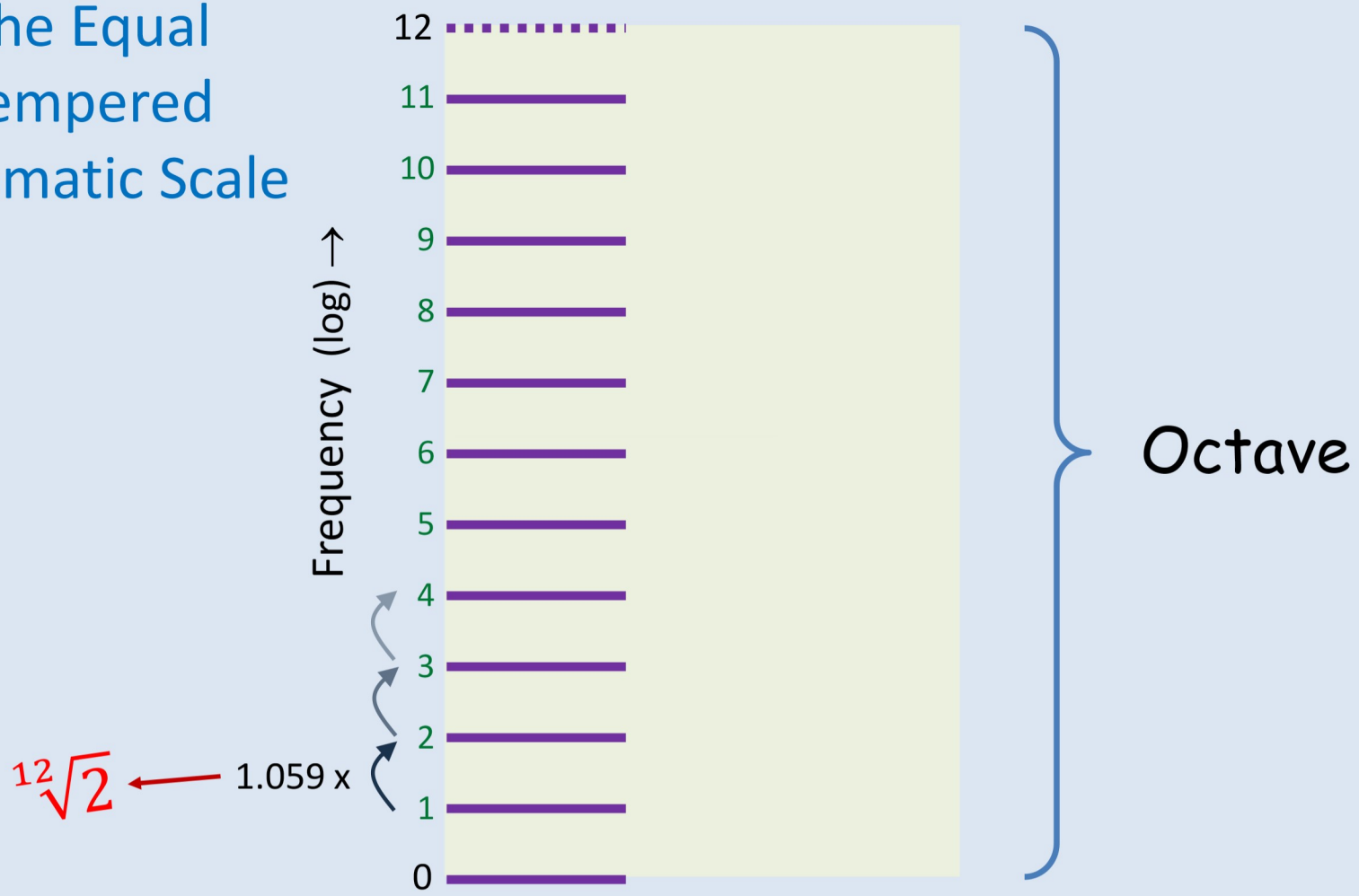




Intonation and Temperament Timeline in Western Music



The Equal Tempered Chromatic Scale



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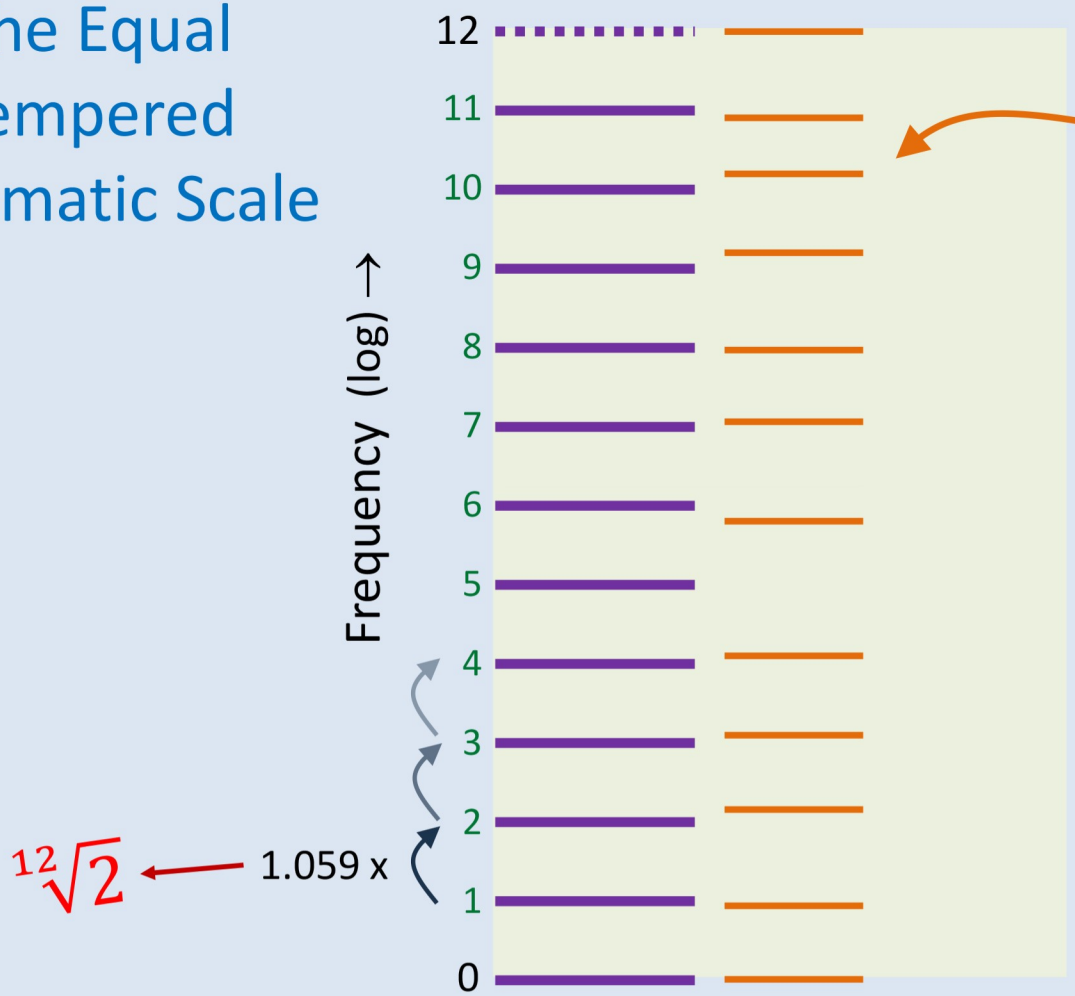
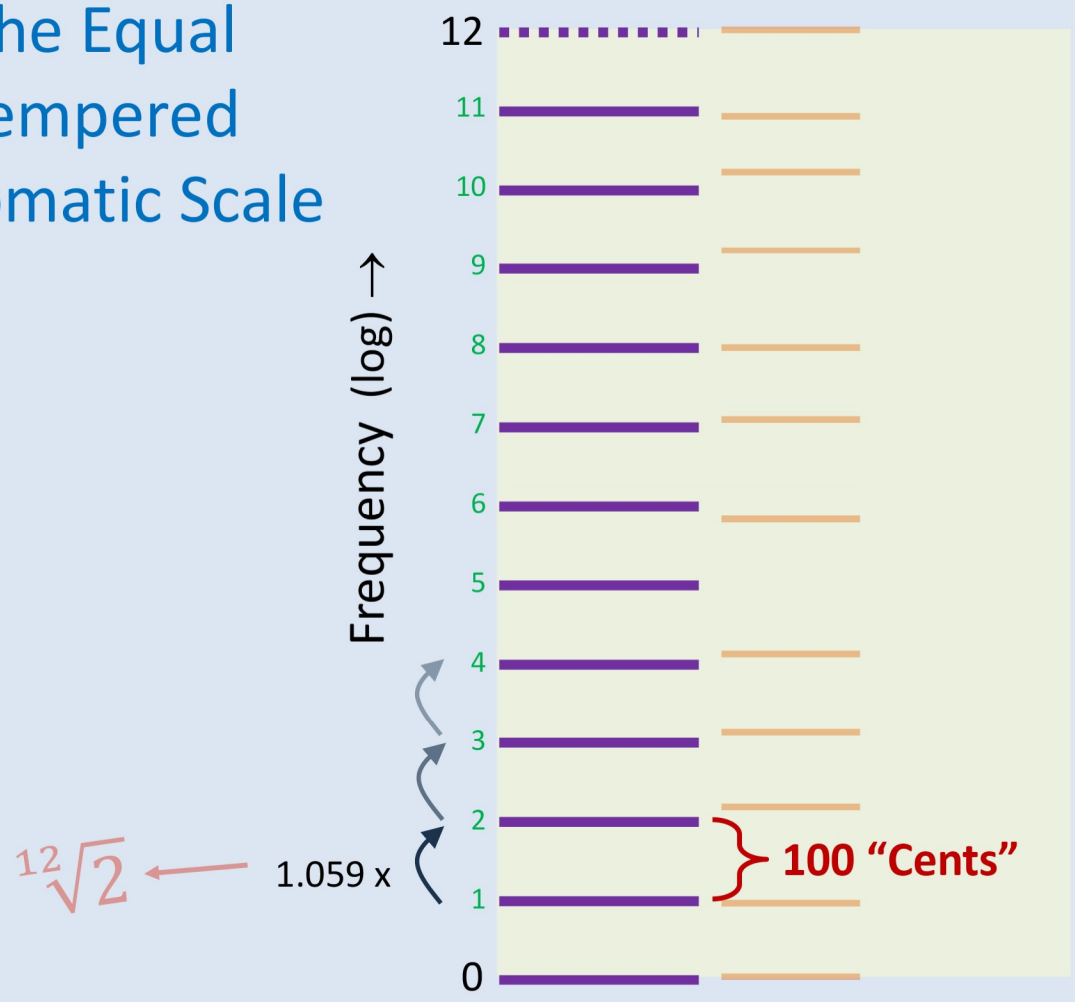


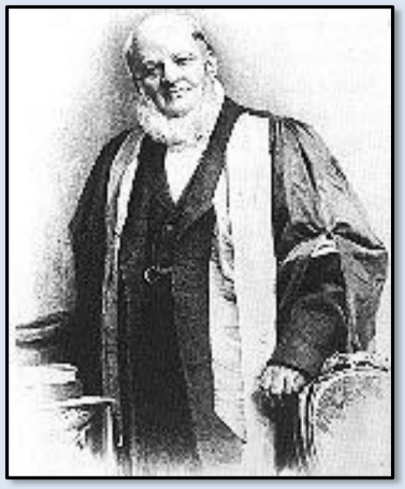
Alternate **Intonation** *or* **Temperament**

A *Different* Choice of Frequencies

Octave

The Equal Tempered Chromatic Scale





Alexander J. Ellis

English Mathematician & Philologist

(1814-1890)

Invented "Cents" (1885) to measure frequency intervals

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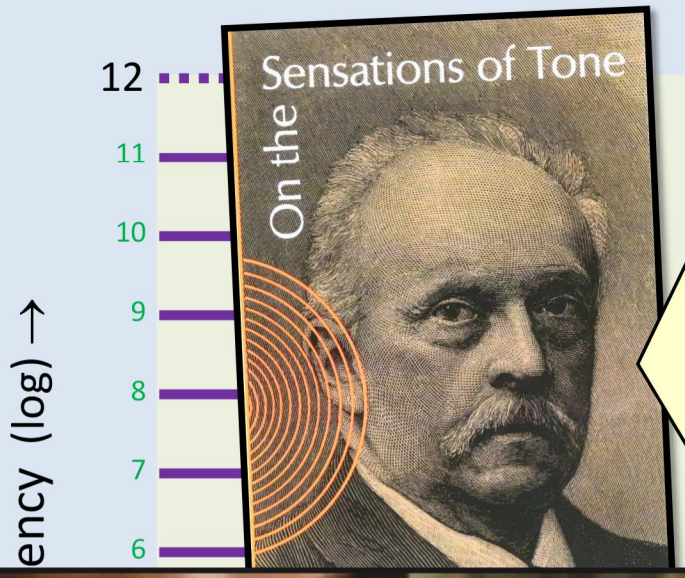
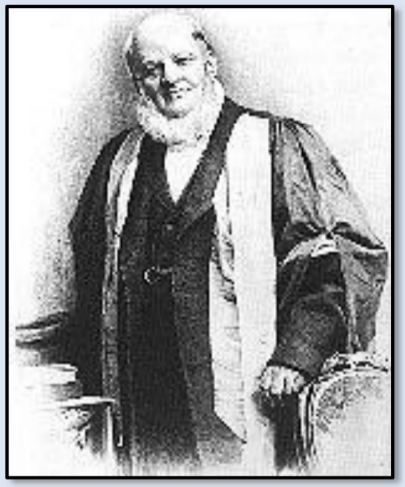


English Translation of Helmholtz



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George Bernard Shaw's Inspiration for Prof. Higgens

$\sqrt[12]{2}$ ←

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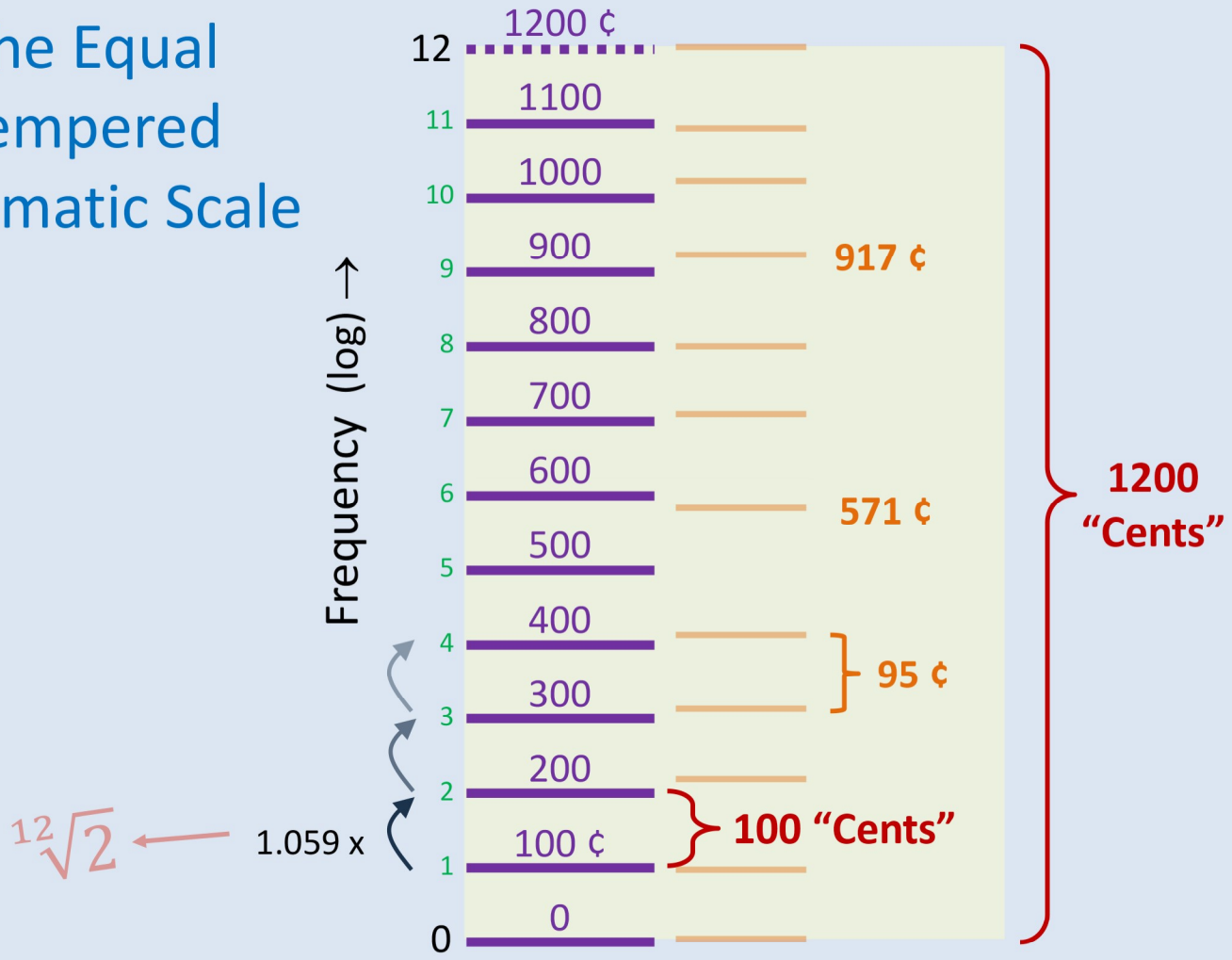

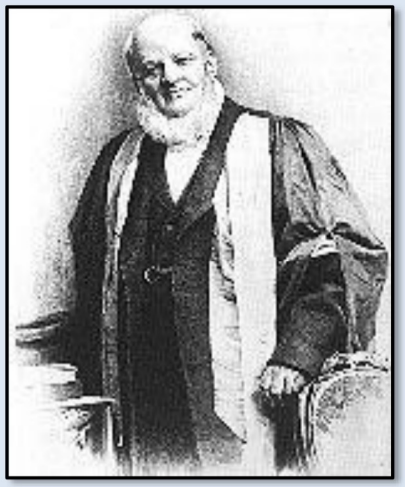

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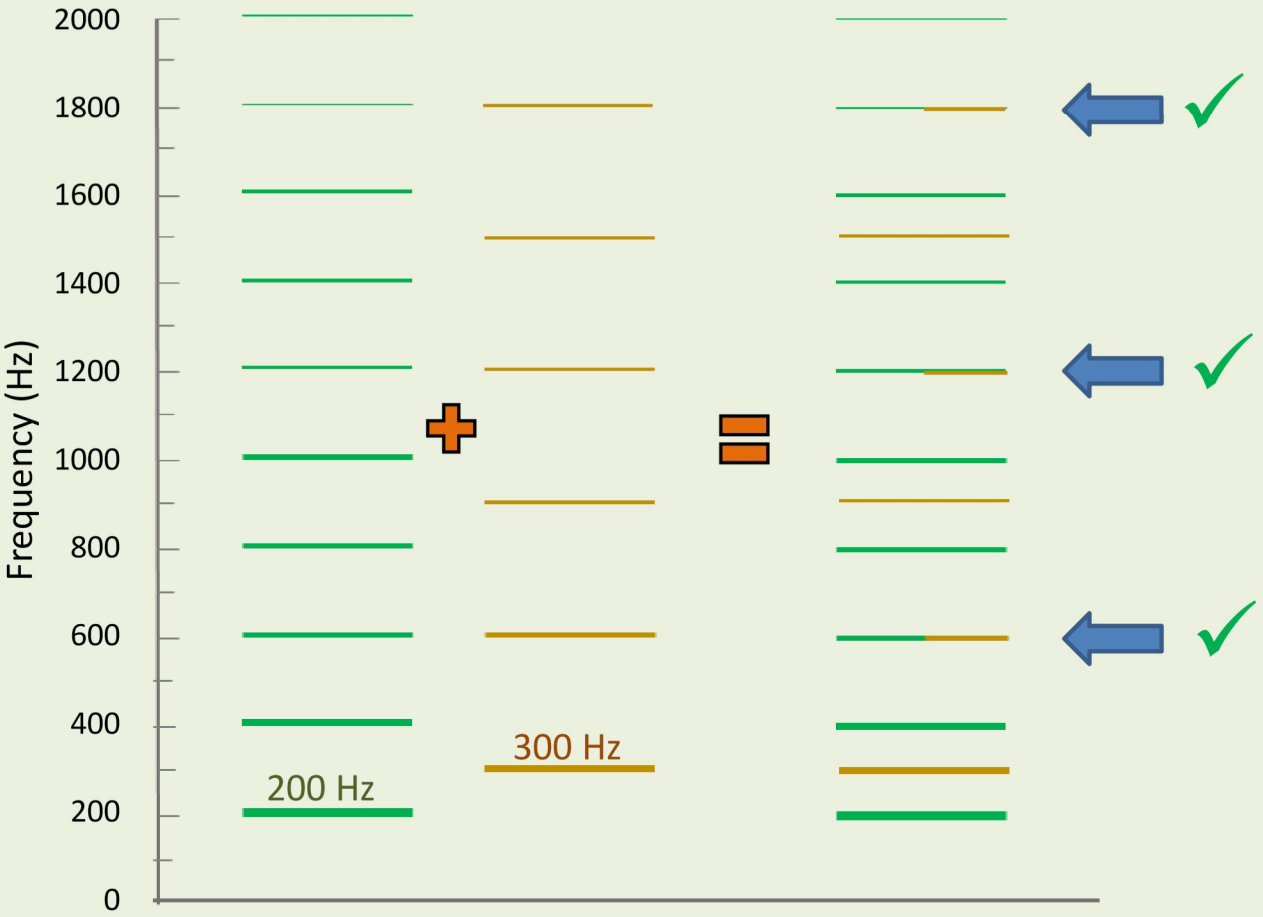
CONSONANCE

vs

Dissonance

Remember The “Power Chord” ?



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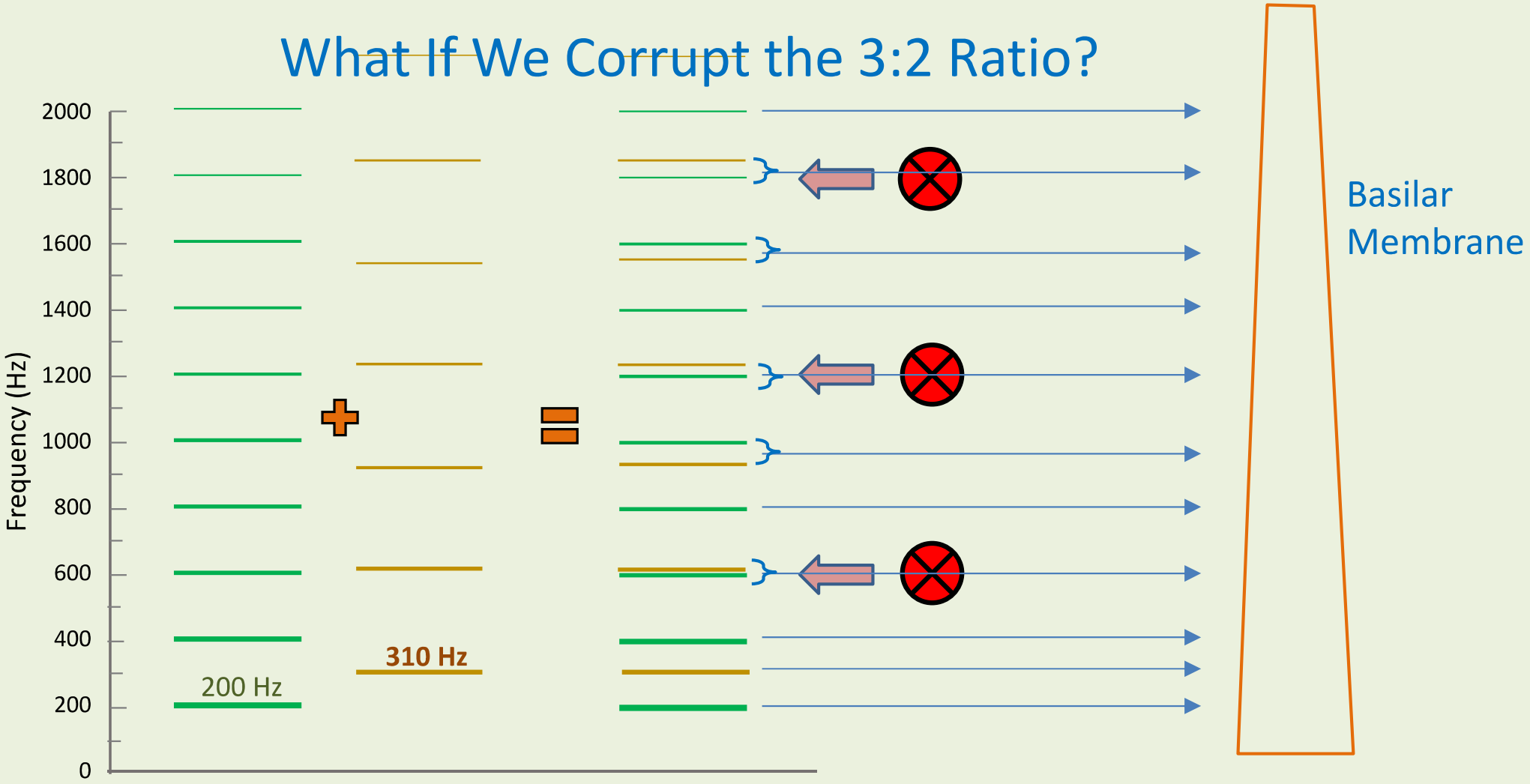
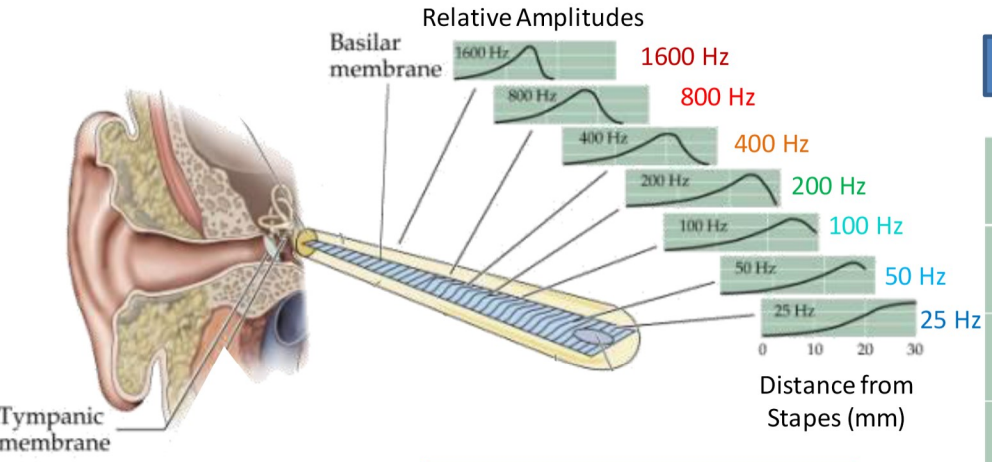
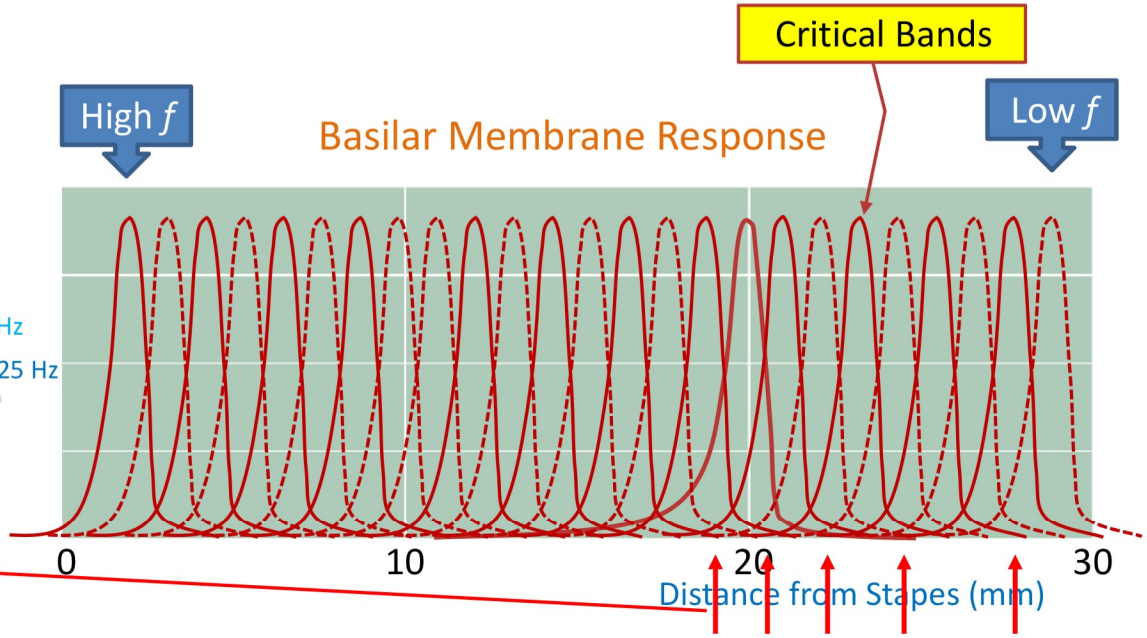
- **3:2** Frequency Ratio
- Also called “Fifth Chord” *or* “Open Fifth Chord”

What If We Corrupt the 3:2 Ratio?



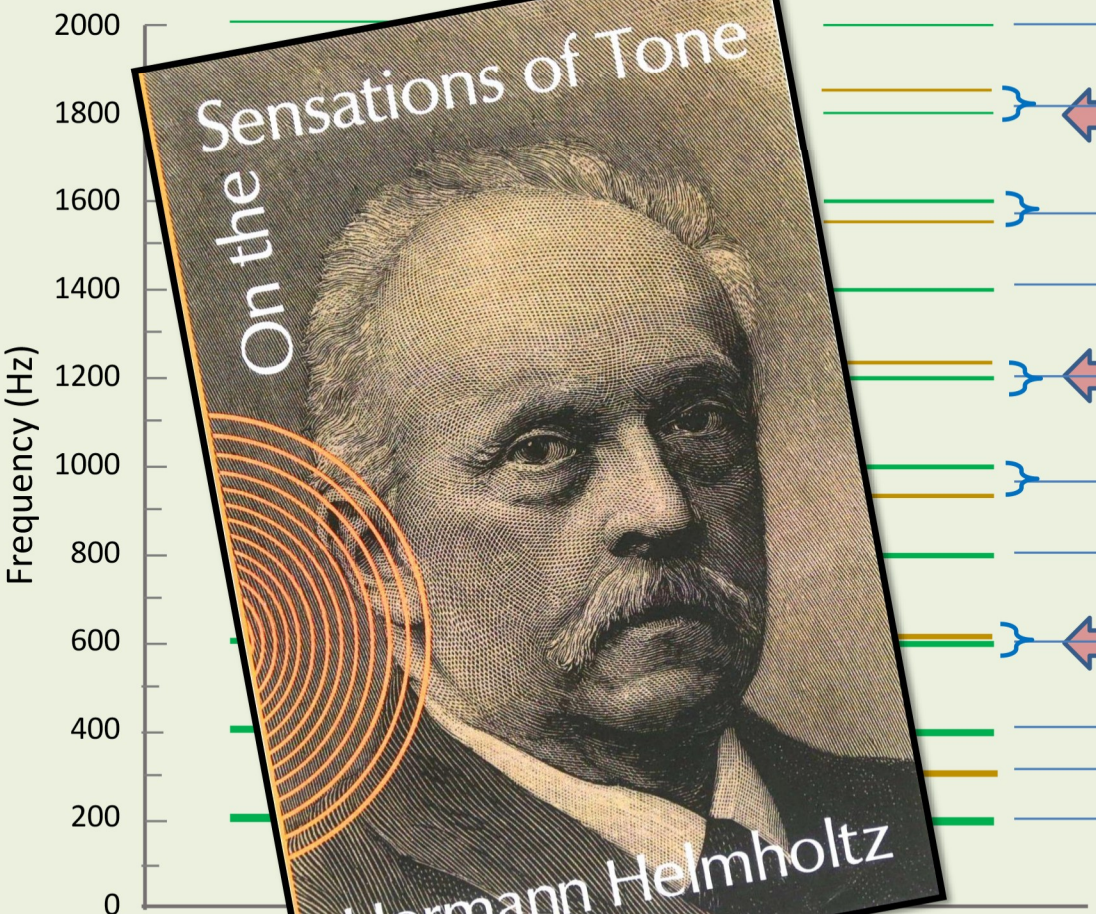
It's the Basilar Membrane, As We Know

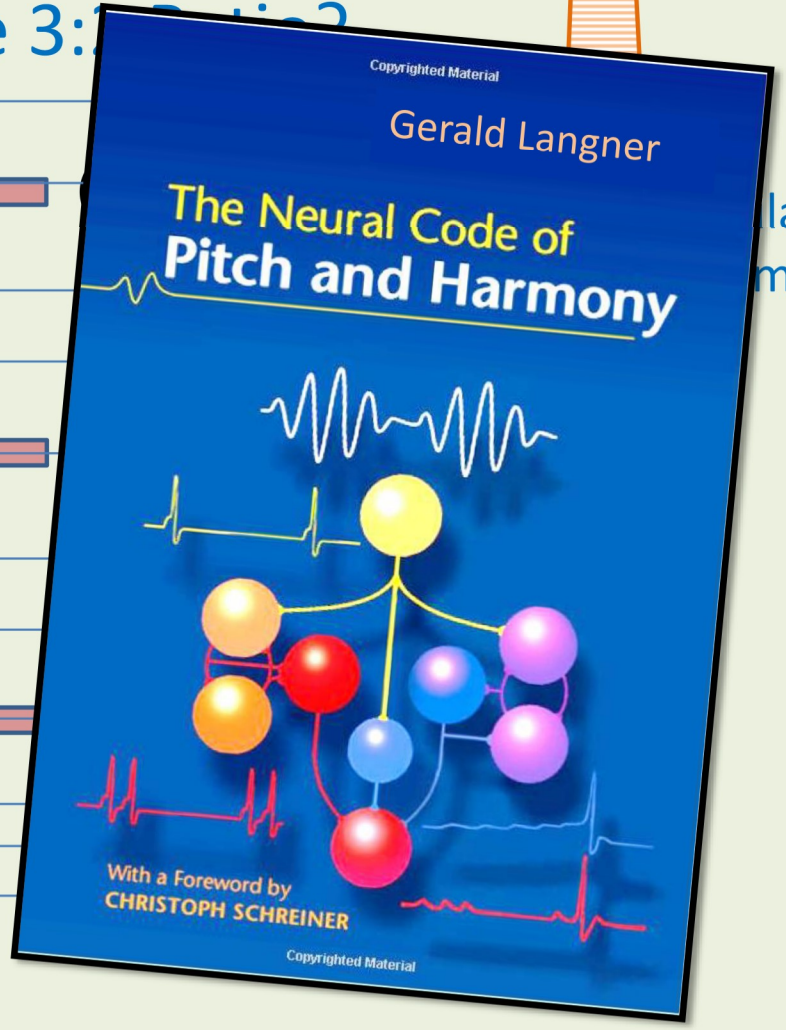




Lower Harmonics Fall on *Different* Critical Bands

What If We Corrupt the 3:2 Ratio?

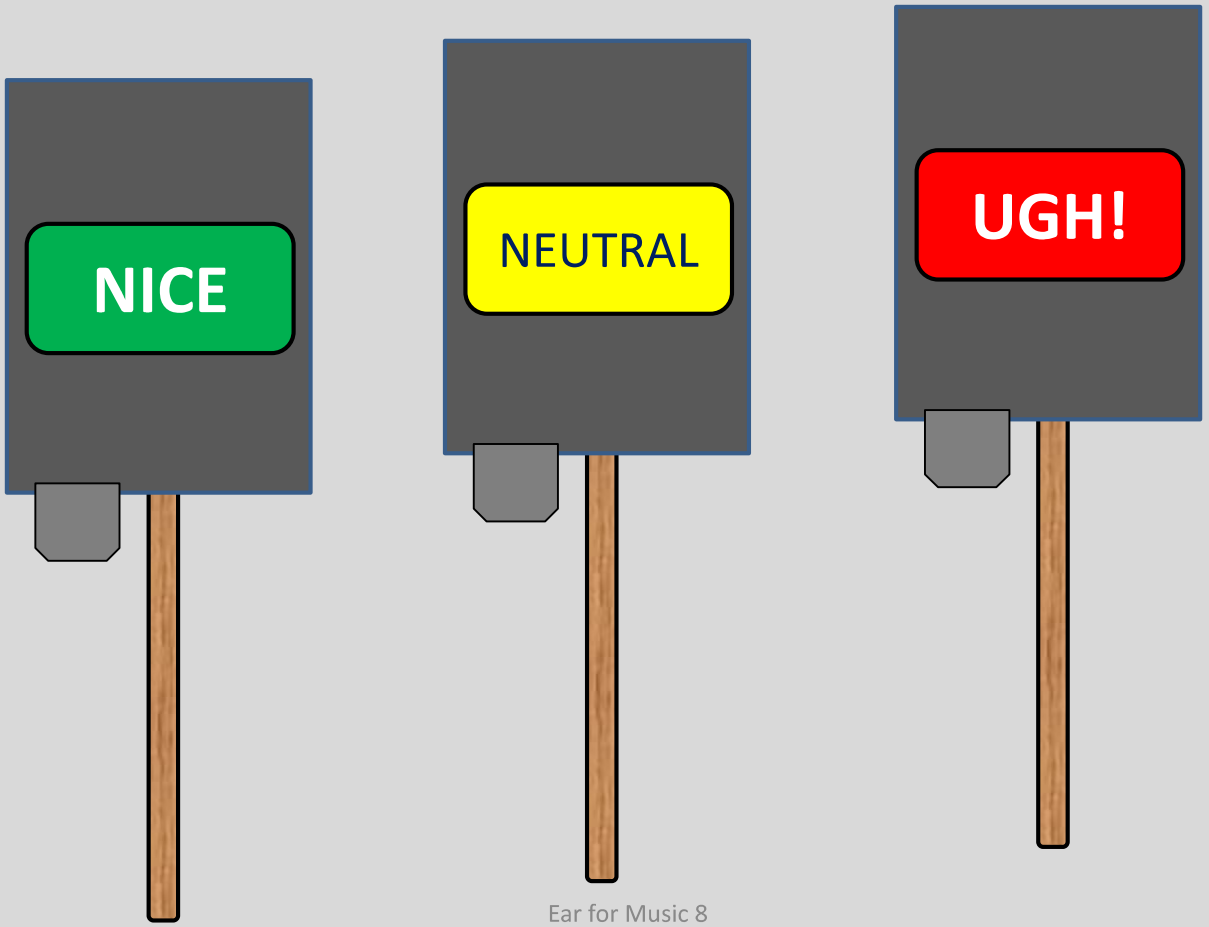




lar

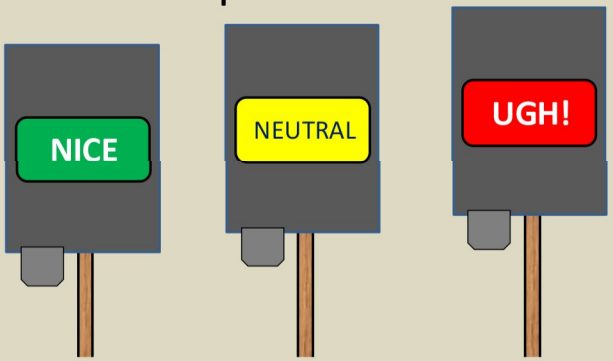
mbrane

OLLI-Vote Wands



Consonance Experiment

- You will hear 2 complex tones played simultaneously
- Relax and Judge the ***Pleasantness*** of the pair
  - **Green** = Quite Pleasant
  - **Yellow** = So-so
  - **Red** = Less Pleasant



First, a Sample to get calibrated.
This is in the mid-range.

3×

Hand out forms to record responses

Tone Pair Ratings

320 Hz *vs* Other Tone

(Complex Tones)

Tone Pair #	Nice	OK	Bad
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			

Wolf Fifths

#	Nice	Wolf
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		

Consonance Experiment

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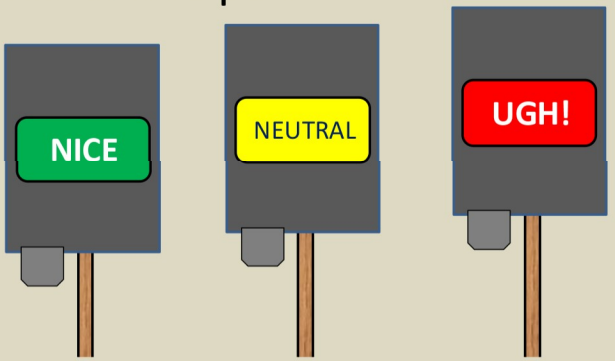


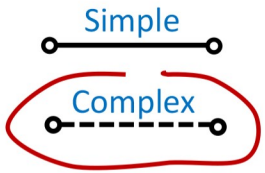
1	2	3	4	5	6	7	8	9	10	11

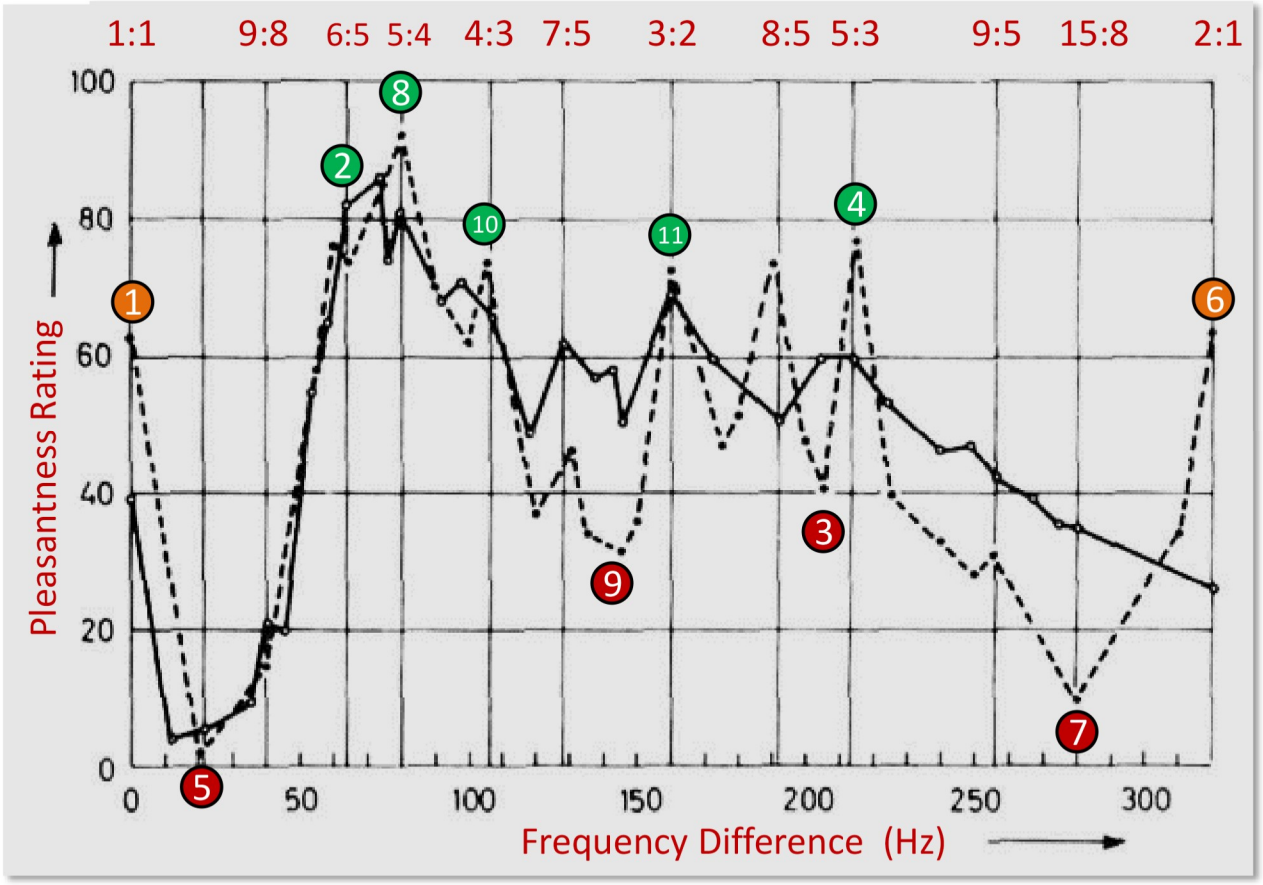
Classic Measurement of Consonance

What you just heard...

Drone:
320 Hz

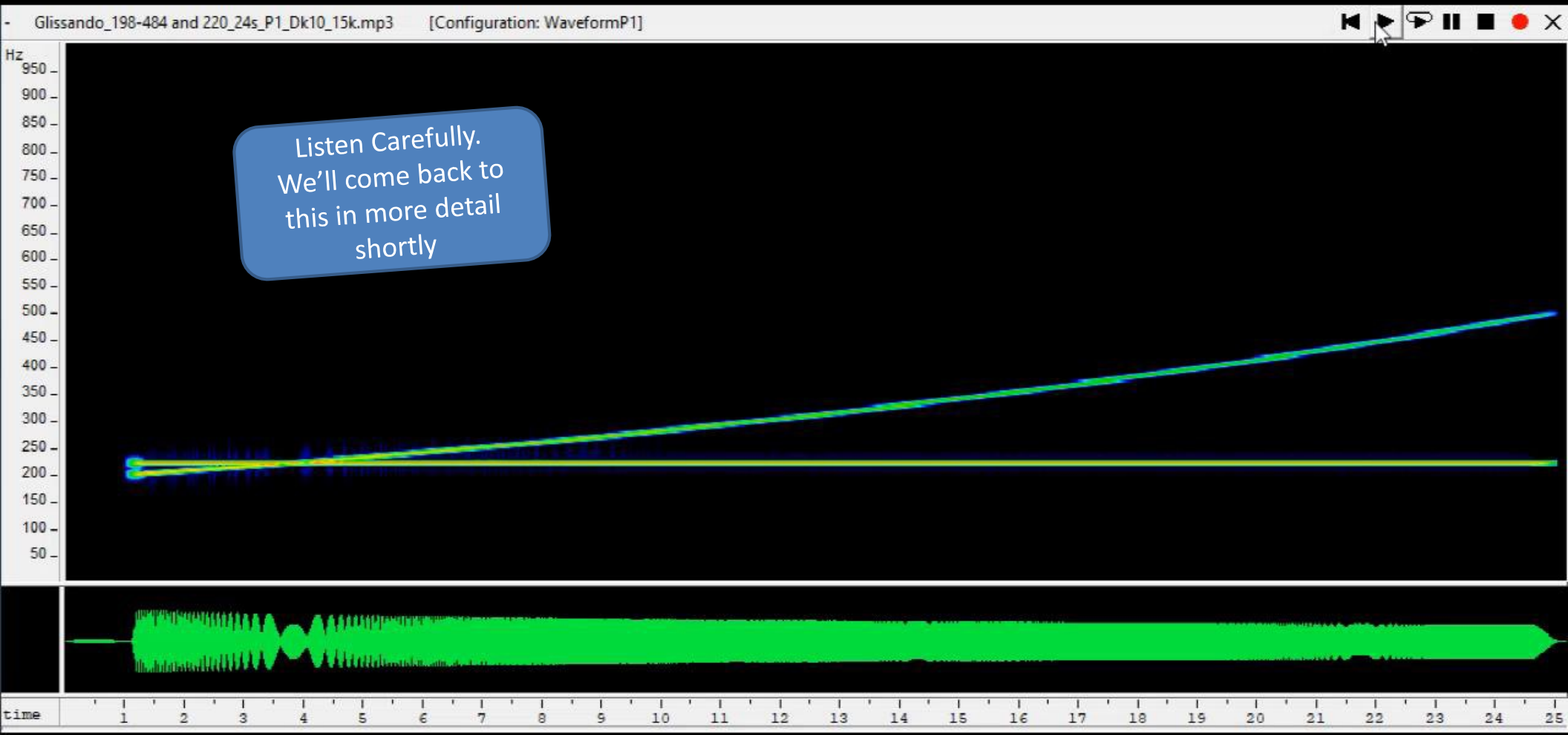
Variable Tone:
320-640 Hz



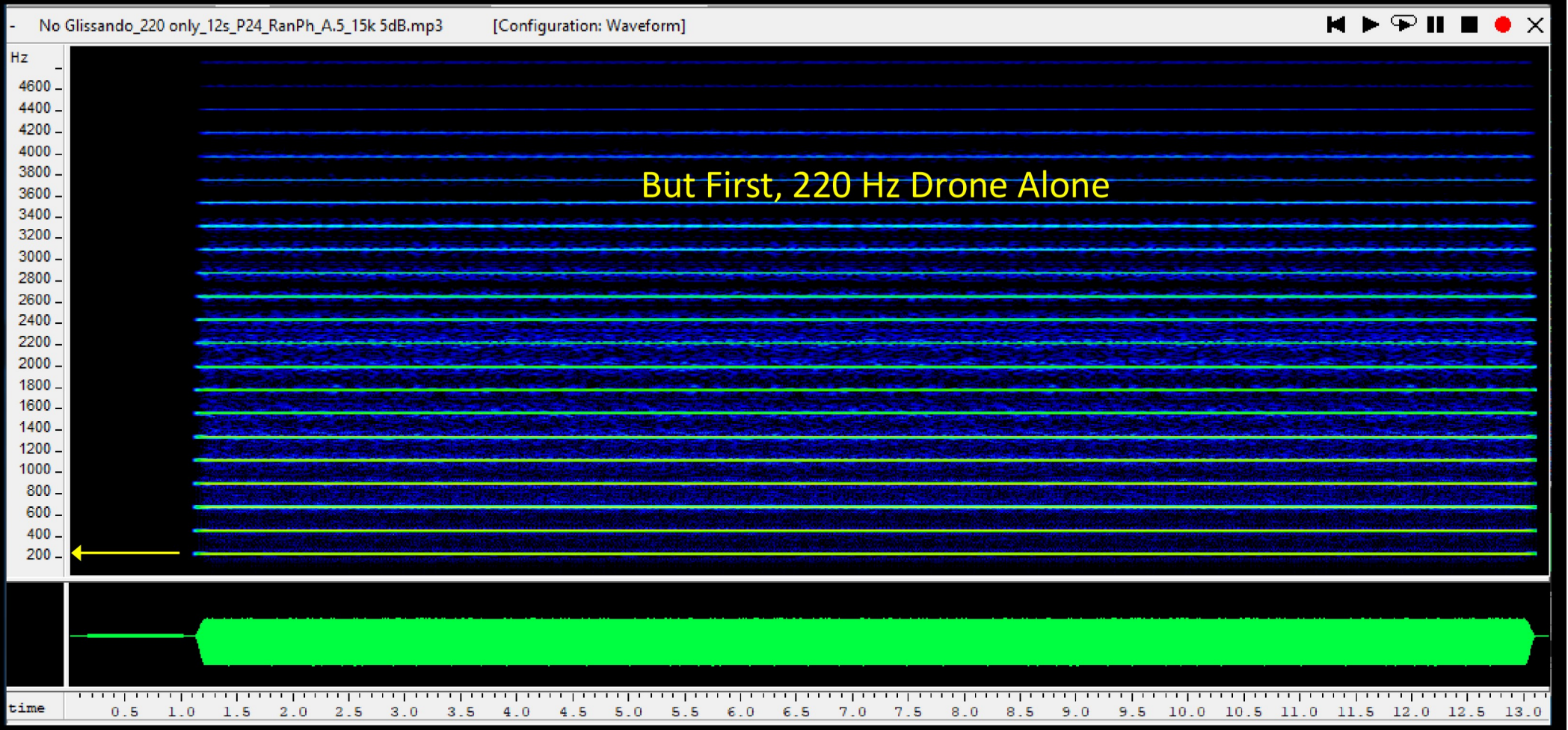


Plomp & Levelt
Tonal Consonance and Critical Bandwidth
J Acoustical Soc of Am (1965)
[Orig data from G. Kaestner, 1909]

Consonance of ***Simple*** Tones: 220 Hz Drone *vs.* Variable Frequency over an Octave



Mixing Two ***Complex*** Tones: 220 Hz Drone + Increasing Tone, 24 harmonics



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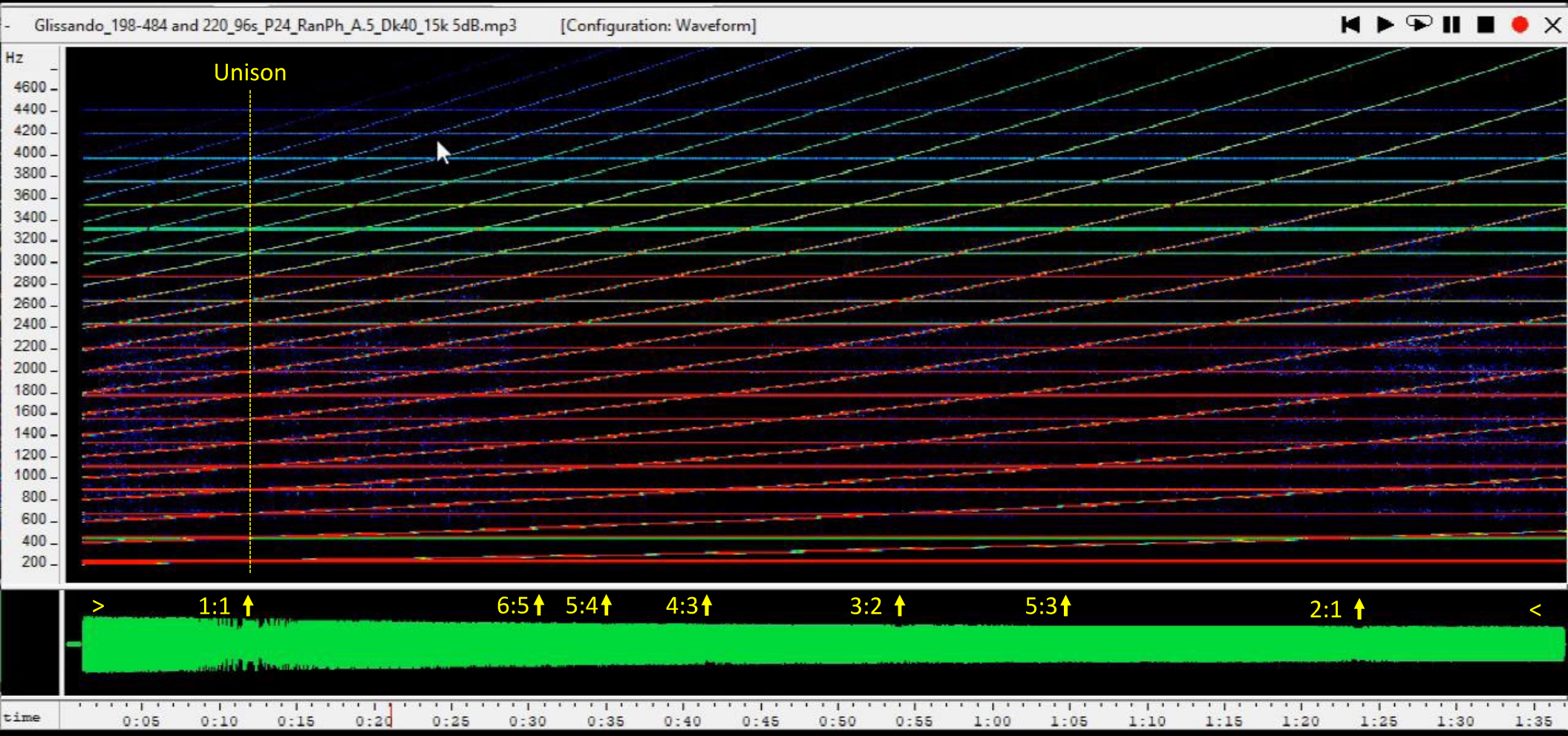

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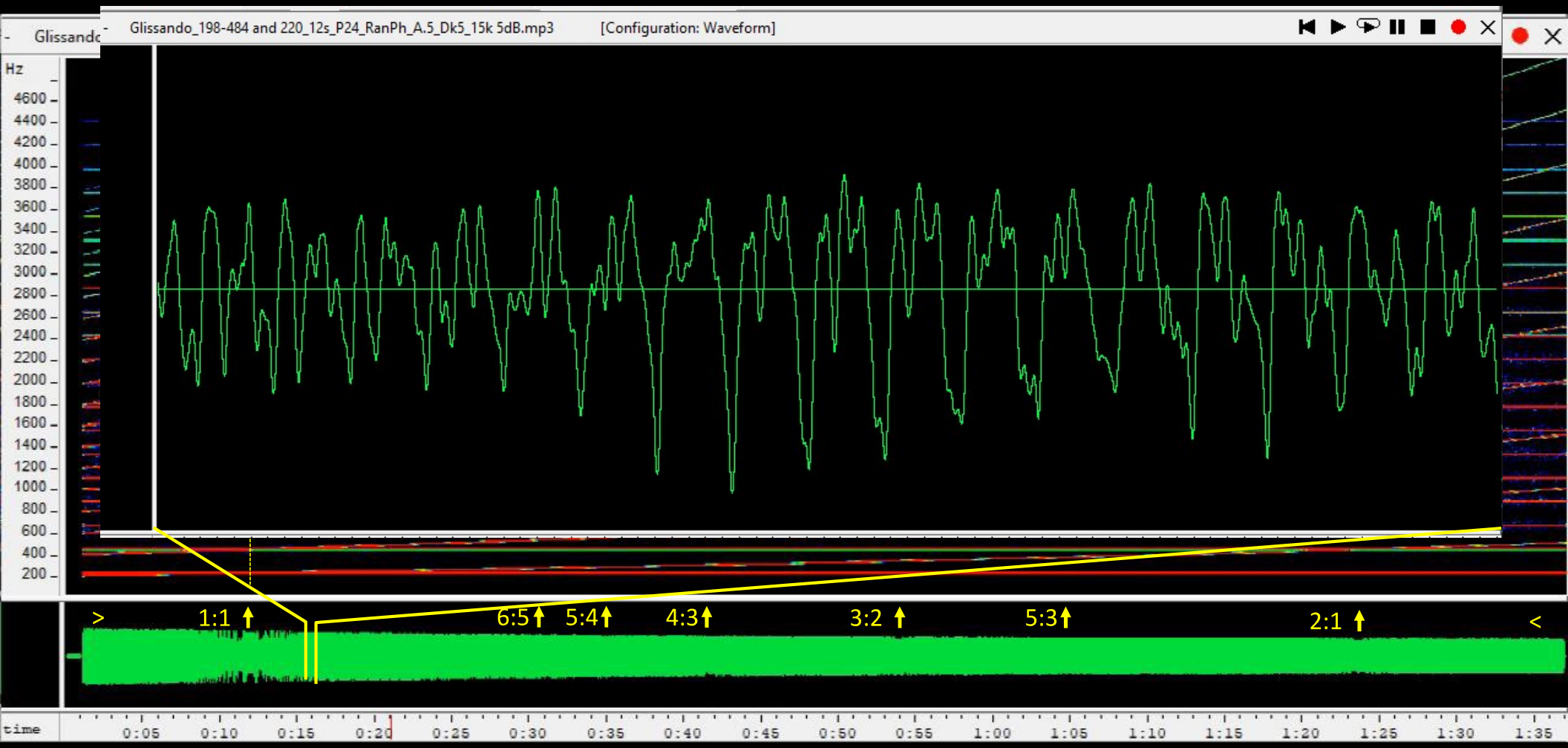


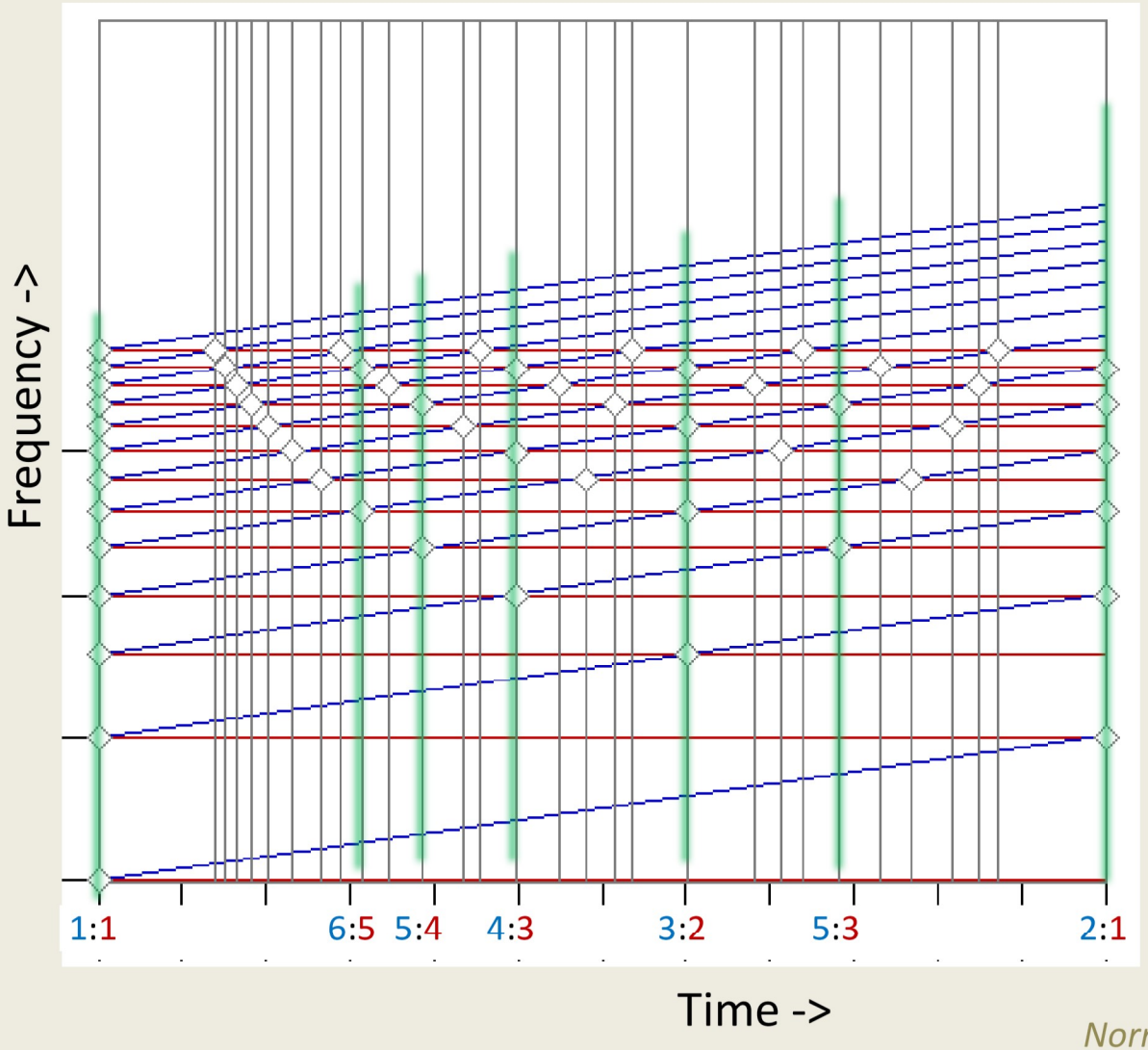
Two-tone Consonance Graph

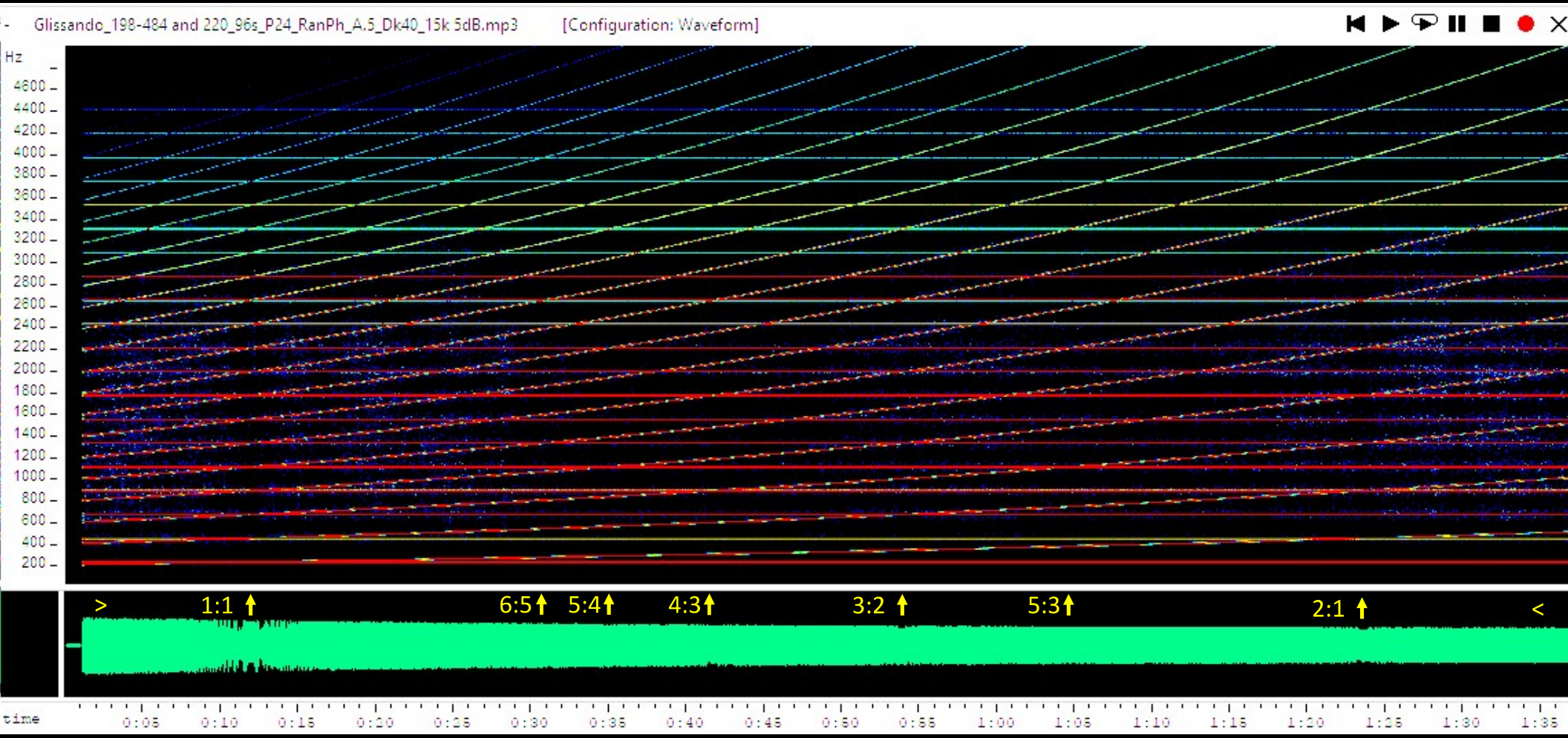
12 Harmonics, Log-Log Scales

Red Tone Fixed

Blue Tone Increases by 1 Octave from Left to Right

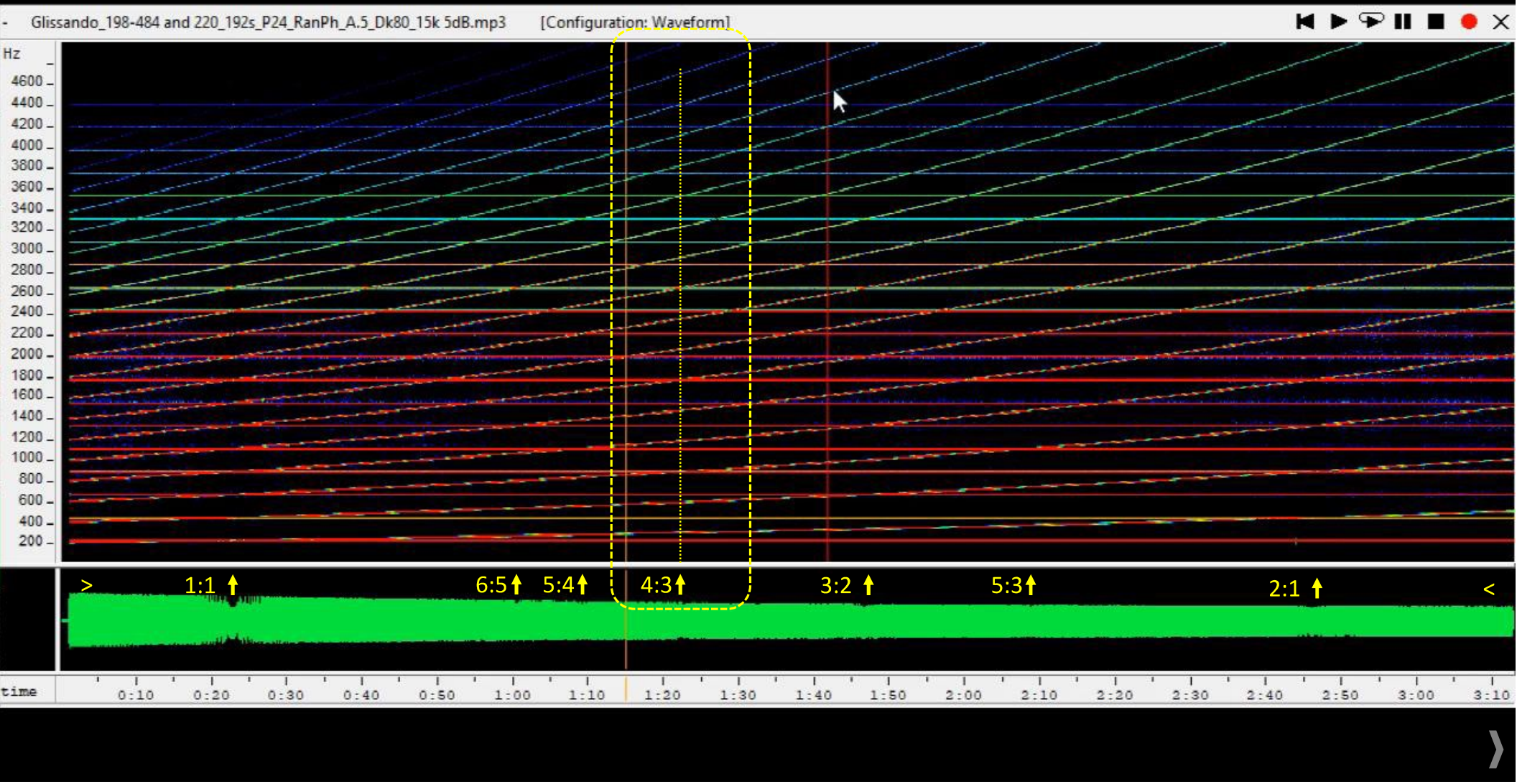
Diamonds ♢ show coincidences of Harmonics leading to Consonances



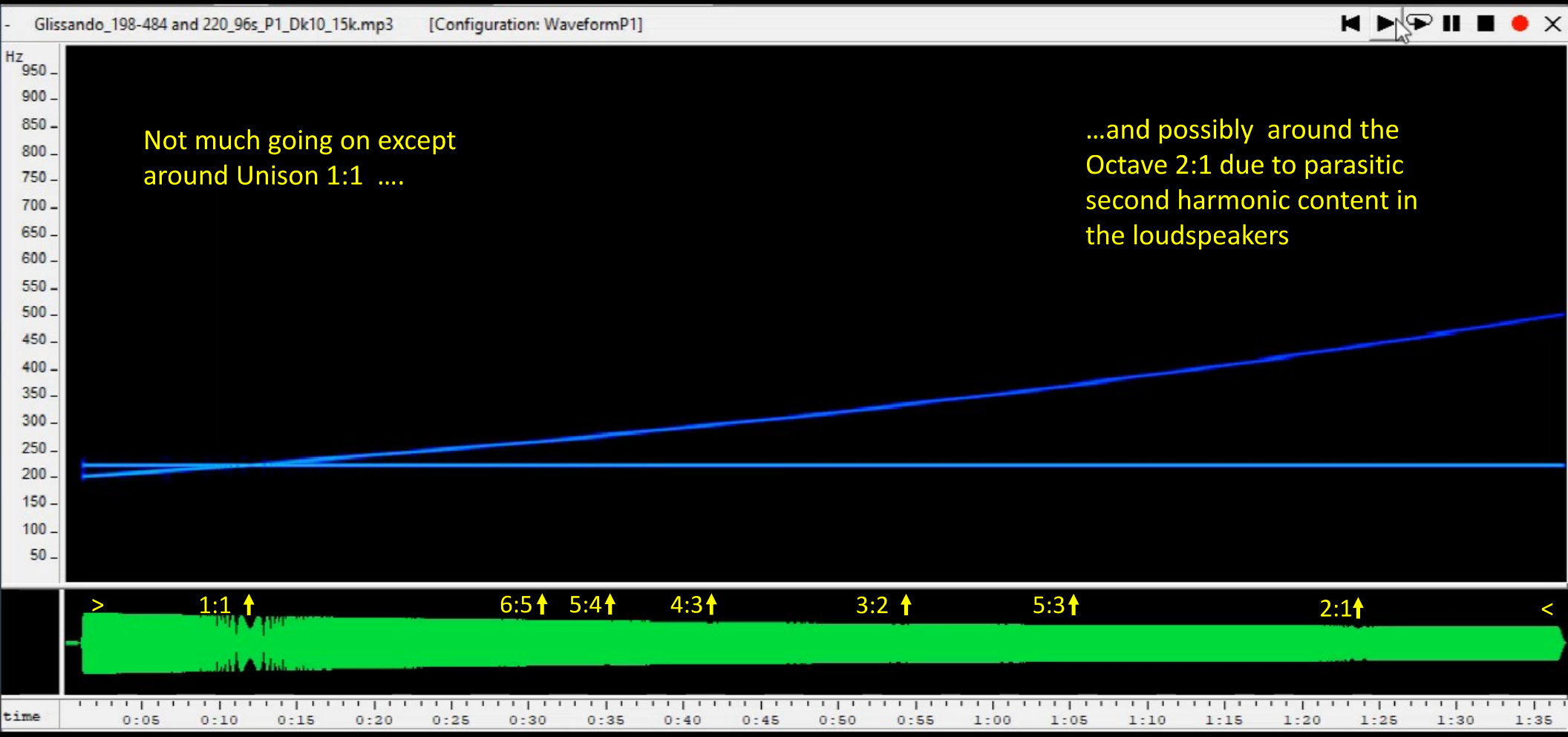

Glissando_198-484 and 220_96s_P24_RanPh_A.5_Dk40_15k 5dB.mp3
[Configuration: Waveform]
Hz
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
>

1:1
6:5
5:4
4:3
3:2
5:3
2:1
<
time
0:05
0:10
0:15
0:20
0:25
0:30
0:35
0:40
0:45
0:50
0:55
1:00
1:05
1:10
1:15
1:20
1:25
1:30
1:35

Mixing Two Complex Tones: Vicinity of ‘Perfect Fourth’ in Slo-Mo



Mixing Two **Simple** Tones: 220 Hz Sine Wave vs Variable Sine Wave



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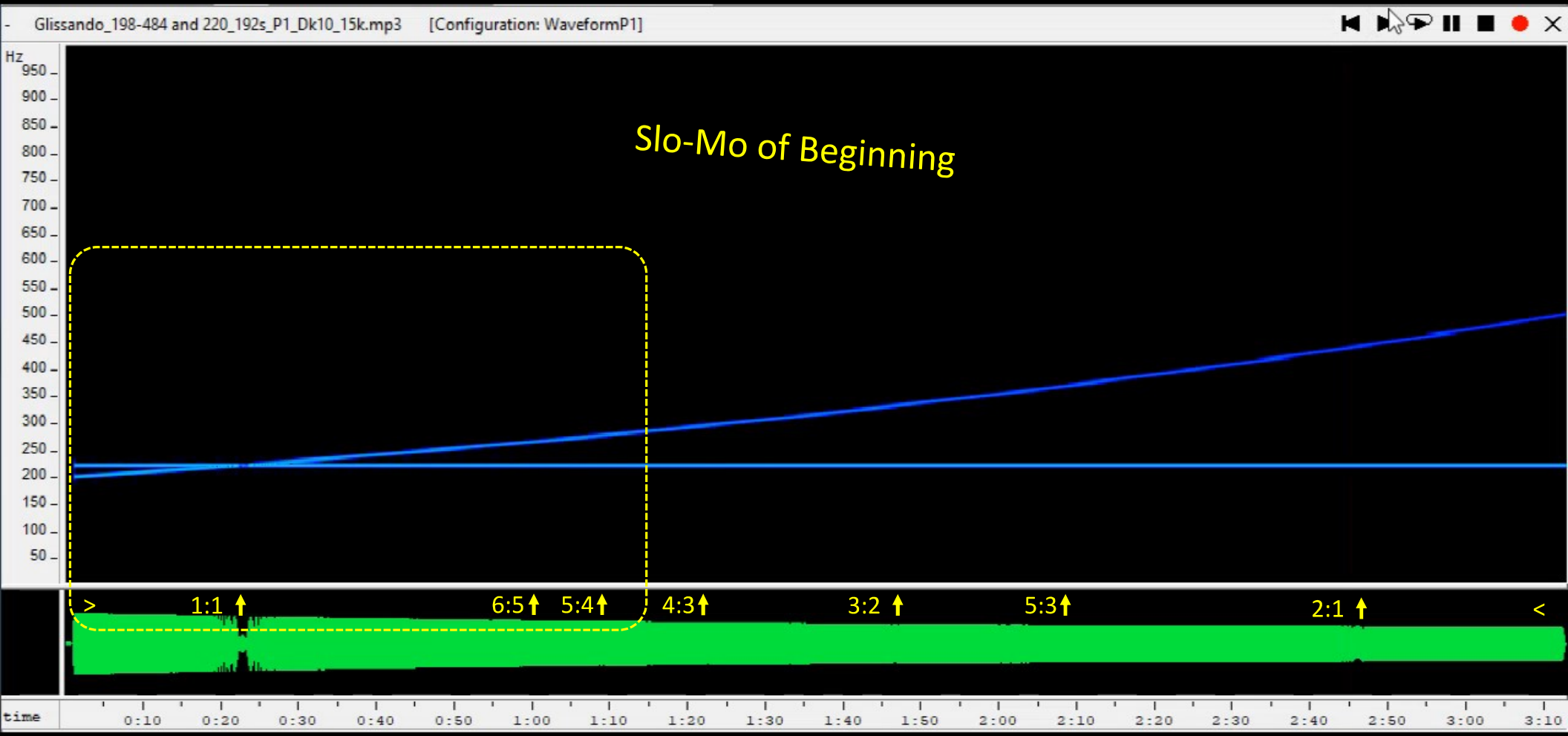
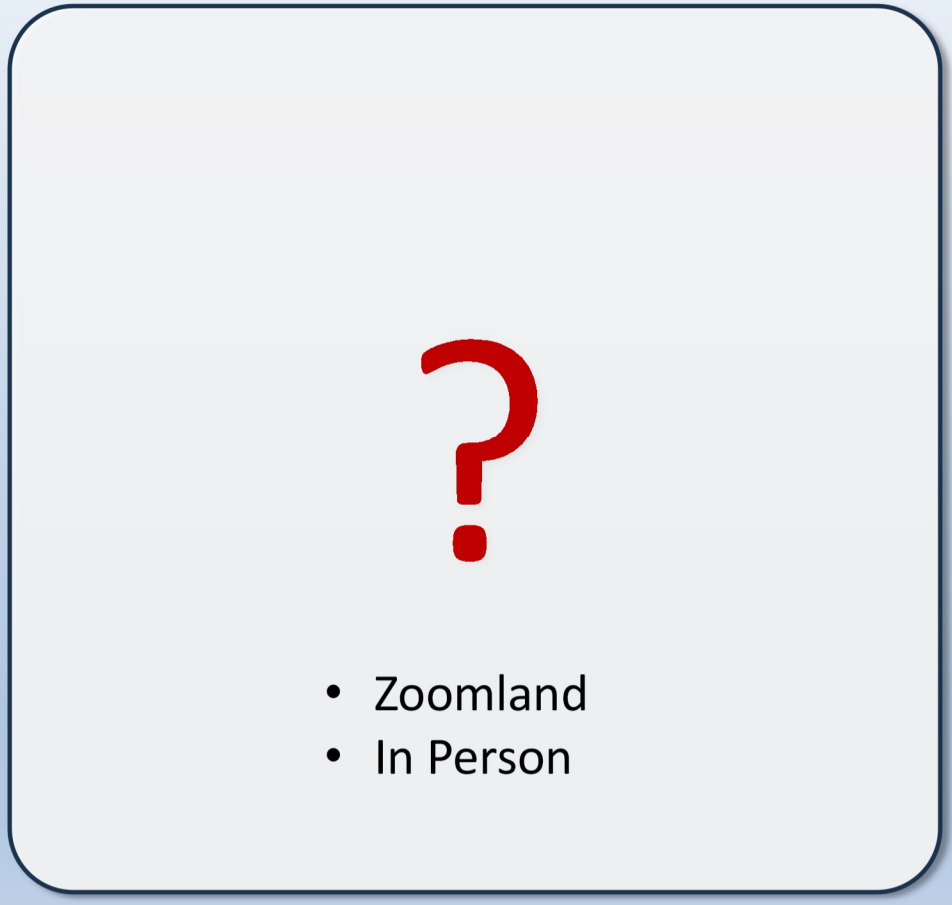


Names of Ratios *(Intervals)*

# Steps on Chromatic Scale	Typical Ratio in $Just_5$ Tuning	Conventional Name	Alternate Name
12	**2:1**	**Perfect Octave**	
11	15:8	Major Seventh	
10	16:9	Minor Seventh	
9	**5:3**	**Major Sixth**	
8	**8:5**	**Minor Sixth**	
7	**3:2**	**Perfect Fifth**	
6	$(\sqrt{2})$	*Diminished Fifth or Augmented Fourth*	Tritone
5	**4:3**	**Perfect Fourth**	
4	**5:4**	**Major Third**	
3	**6:5**	**Minor Third**	
2	9:8	Major Second	Whole Tone
1	16:15	Minor Second	Semitone
0	**1:1**	**Perfect Unison**	

Question Time



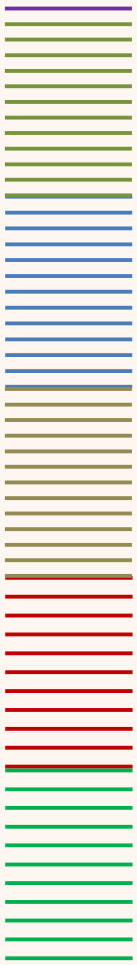
Remember Our Mother Scale?

12 Note Equal Tempered Chromatic Scale

Can we achieve the desired Consonant Ratios between 2 tones?

Log Scale

Frequency $f \rightarrow$



Octave

1200 cents	**200** Hz	**200 Hz**	2:1 “Octave”	1200 ¢
1100	188.8	**187.5**	15:8* “Major Seventh”	1088 ¢
1000	178.2	**177.7**	16:9* “Minor Seventh”	996 ¢
900	168.2	**166.7**	5:3* “Major Sixth”	884 ¢
800	158.7	**160**	8:5* “Minor Sixth”	814 ¢
700	149.8	**150**	3:2 “Perfect Fifth”	702 ¢
600	141.4		?:? “Tritone”	?? ¢
500	133.5	**133.3**	4:3 “Perfect Fourth”	498 ¢
400	126.0	**125**	5:4 “Major Third”	386 ¢
300	118.9	**120**	6:5 “Minor Third”	316 ¢
200	112.2	**112.5**	9:8* “Major Second”	204 ¢
100	105.9	**106.7**	16:15* “Minor Second”	112 ¢
0 cents	**100** Hz	**100 Hz**	1:1 “Unison”	0 ¢

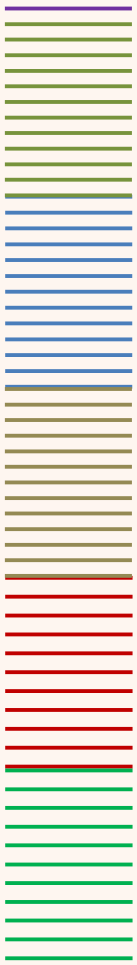
Remember Our Mother Sc
12 Note Equal Tempered Chron e

Error in Cents

Can we achieve the desired Consonant Ratios between 2 tones?

Log Scale

Frequency $f \rightarrow$



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0 cents	**100** Hz	0¢	100 Hz	1:1 “Unison”	0 ¢

2 Things to Remember Today

3:2 = A 'Fifth'

$$\frac{531441}{524288}$$ = The 'Pythagorean Comma'

= 1.0136… = 23.46 cents

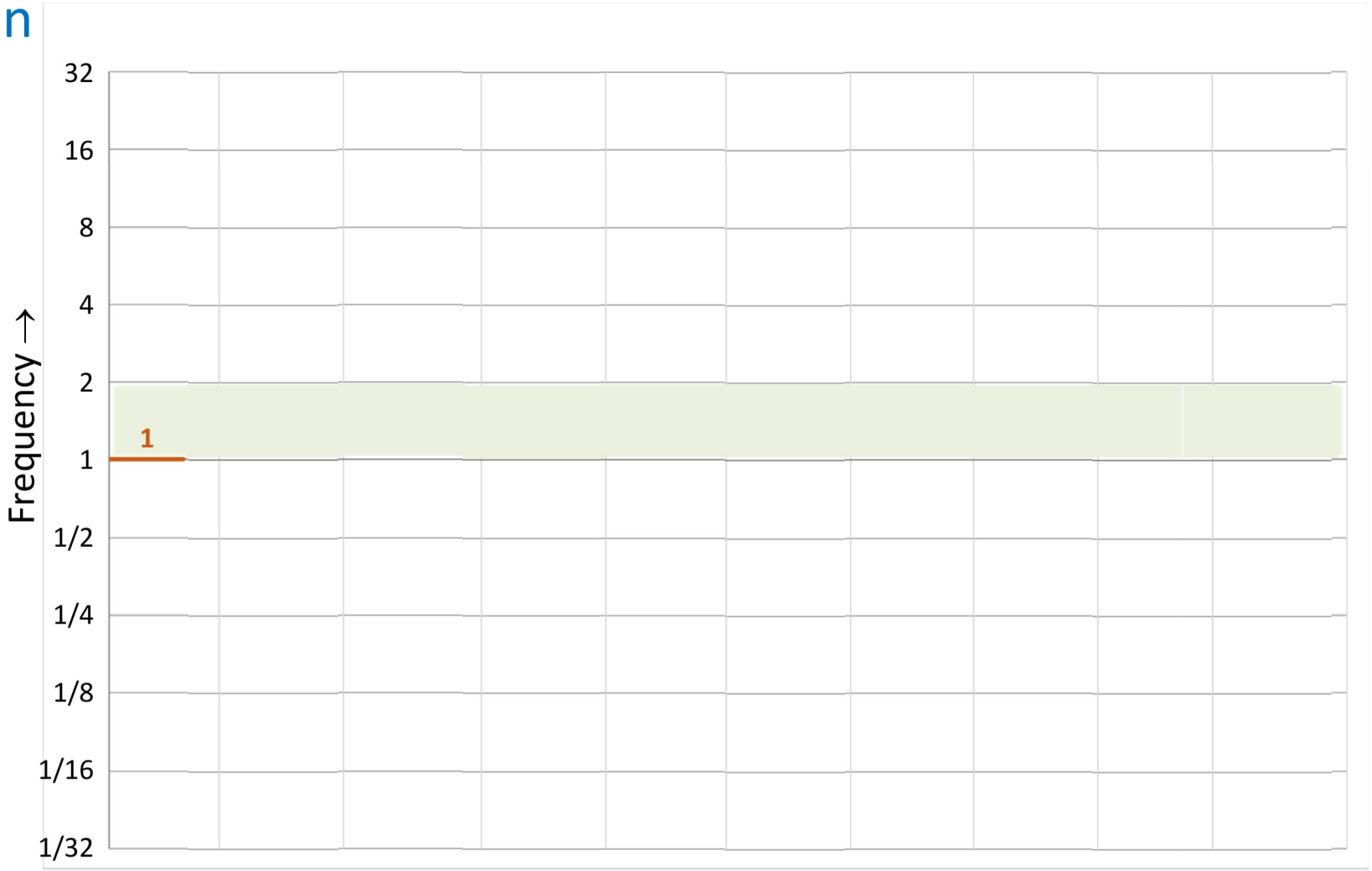
~ Quarter Note

Pythagorean Scales:

Stacking "Fifths"

Keep multiplying by 3/2

…and folding down to base octave



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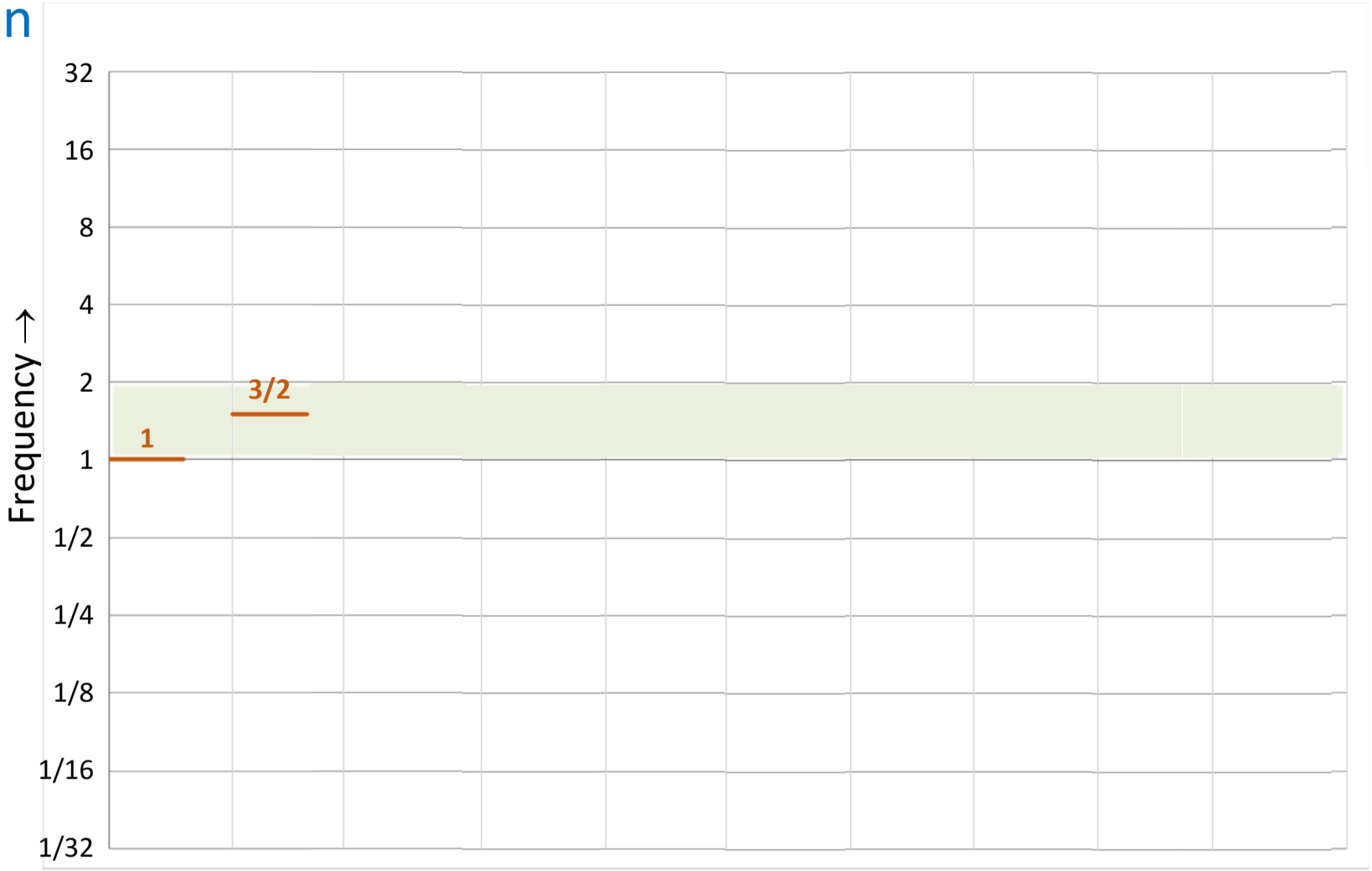

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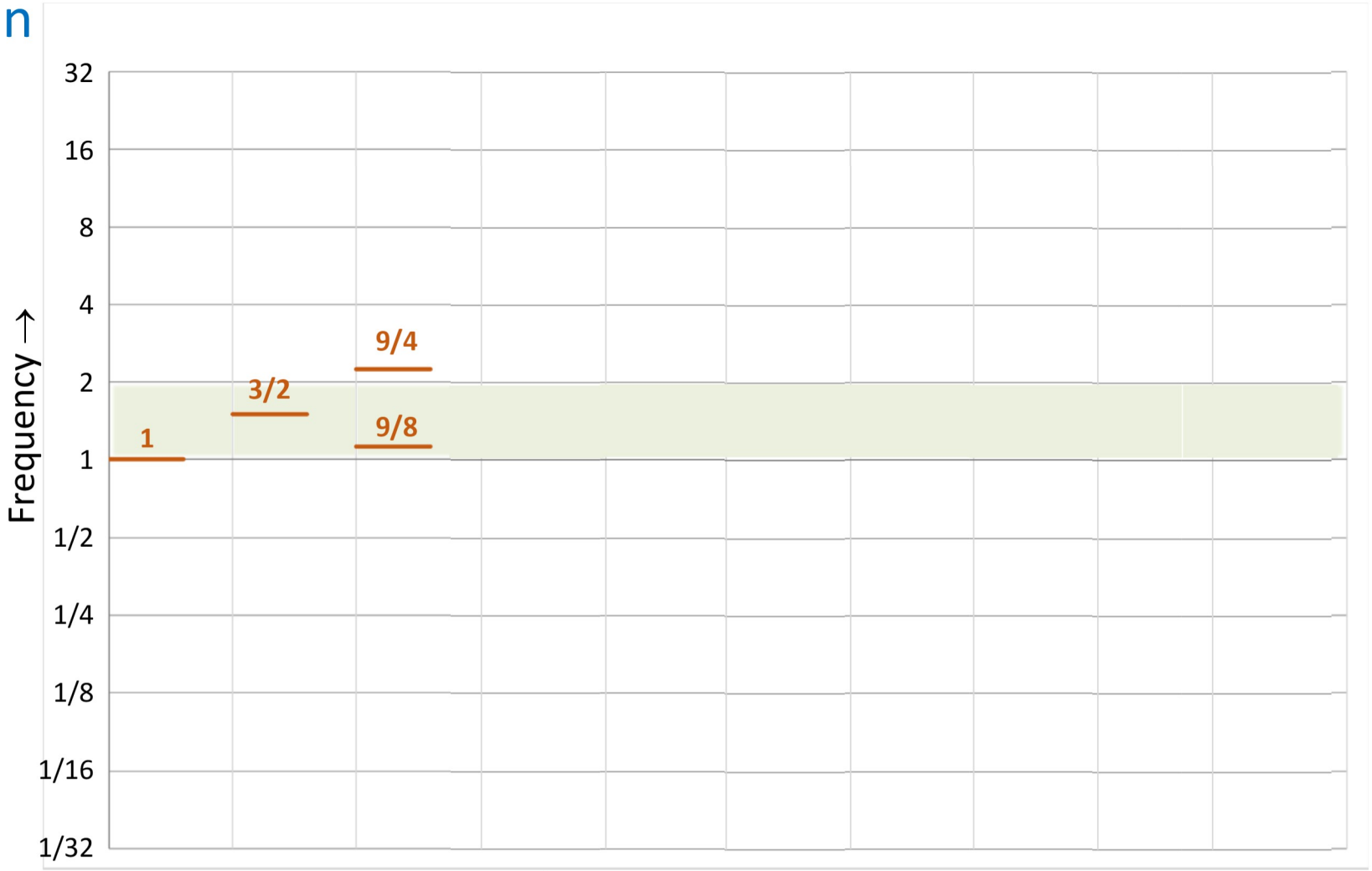

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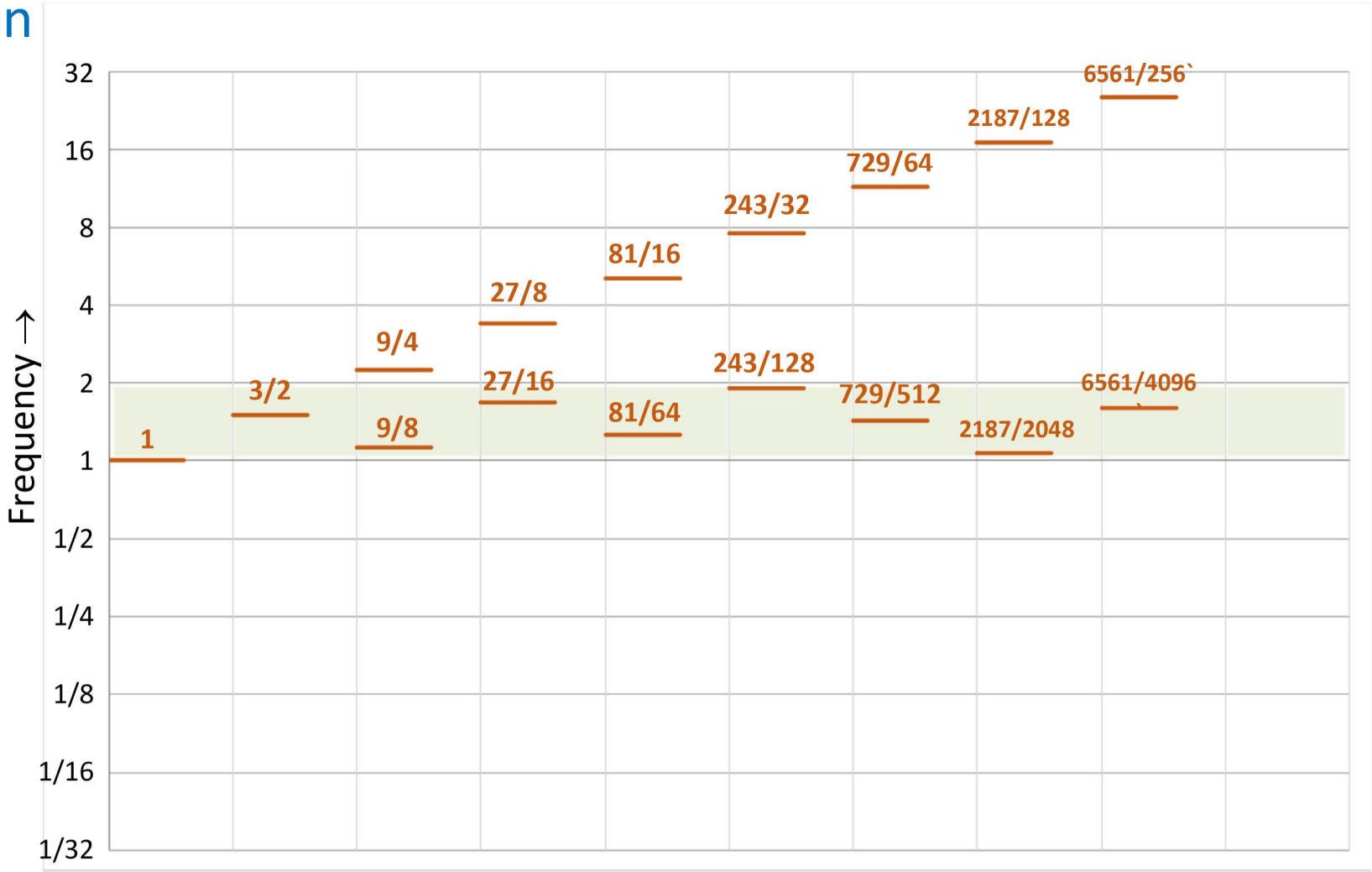

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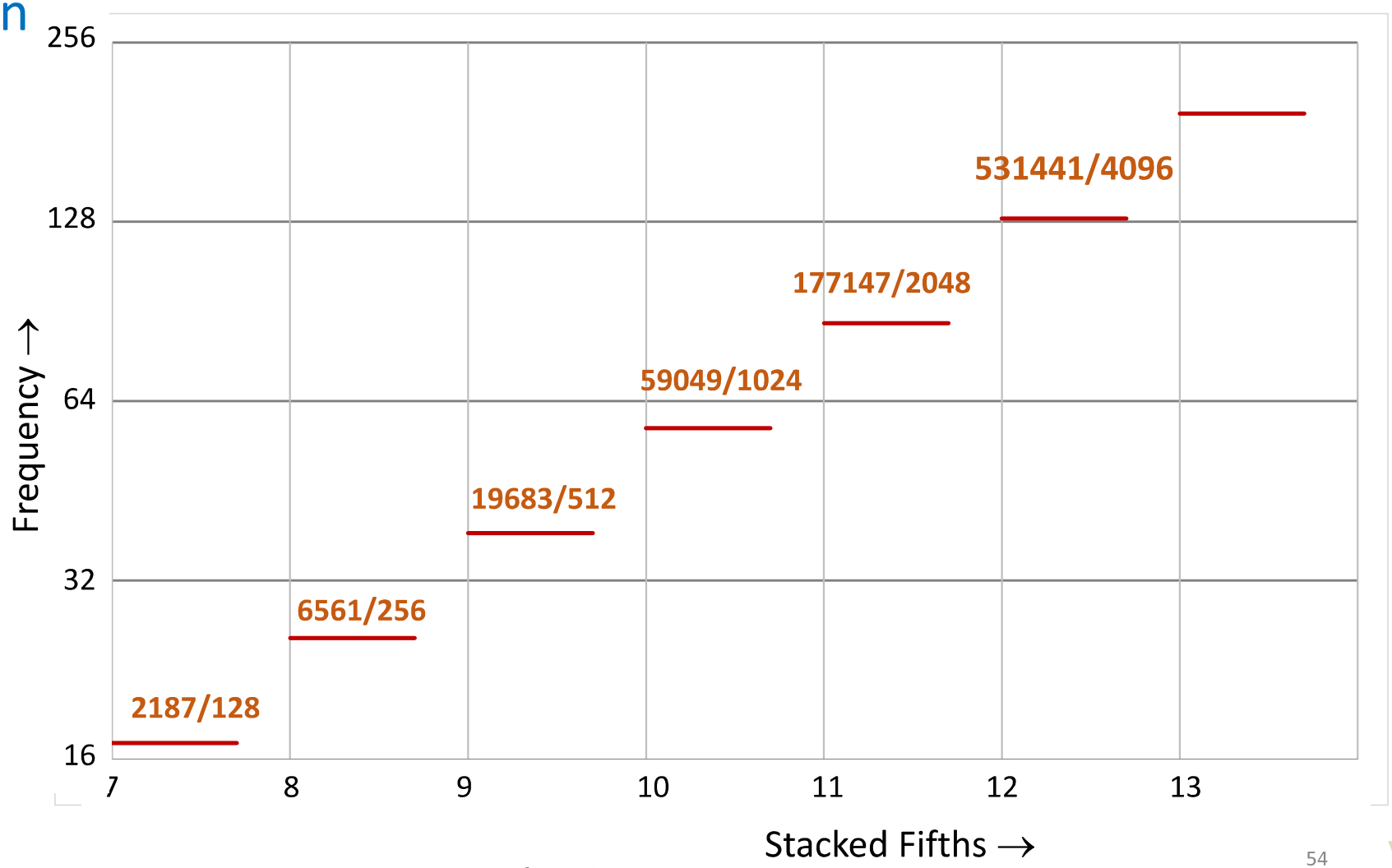

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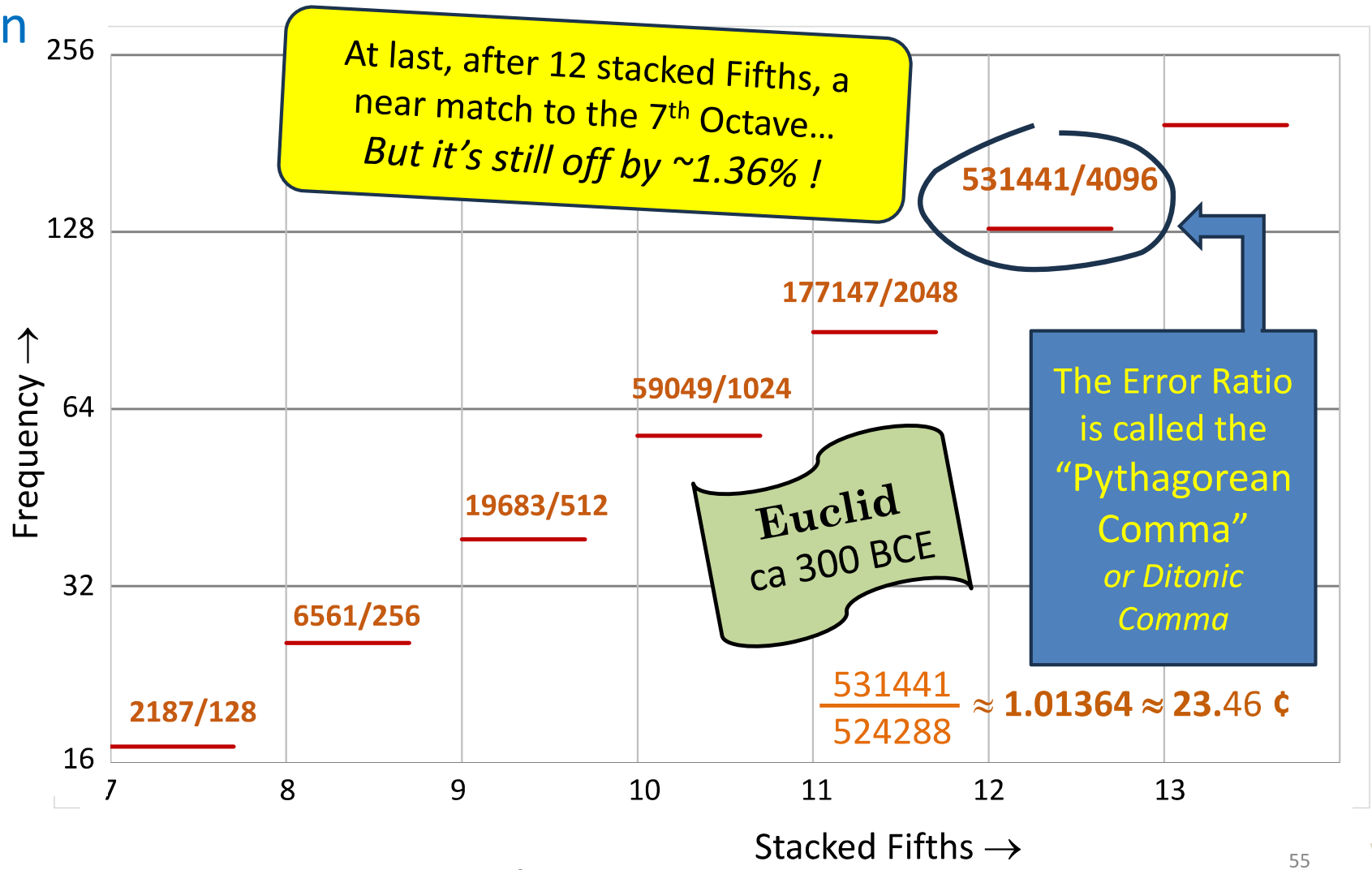
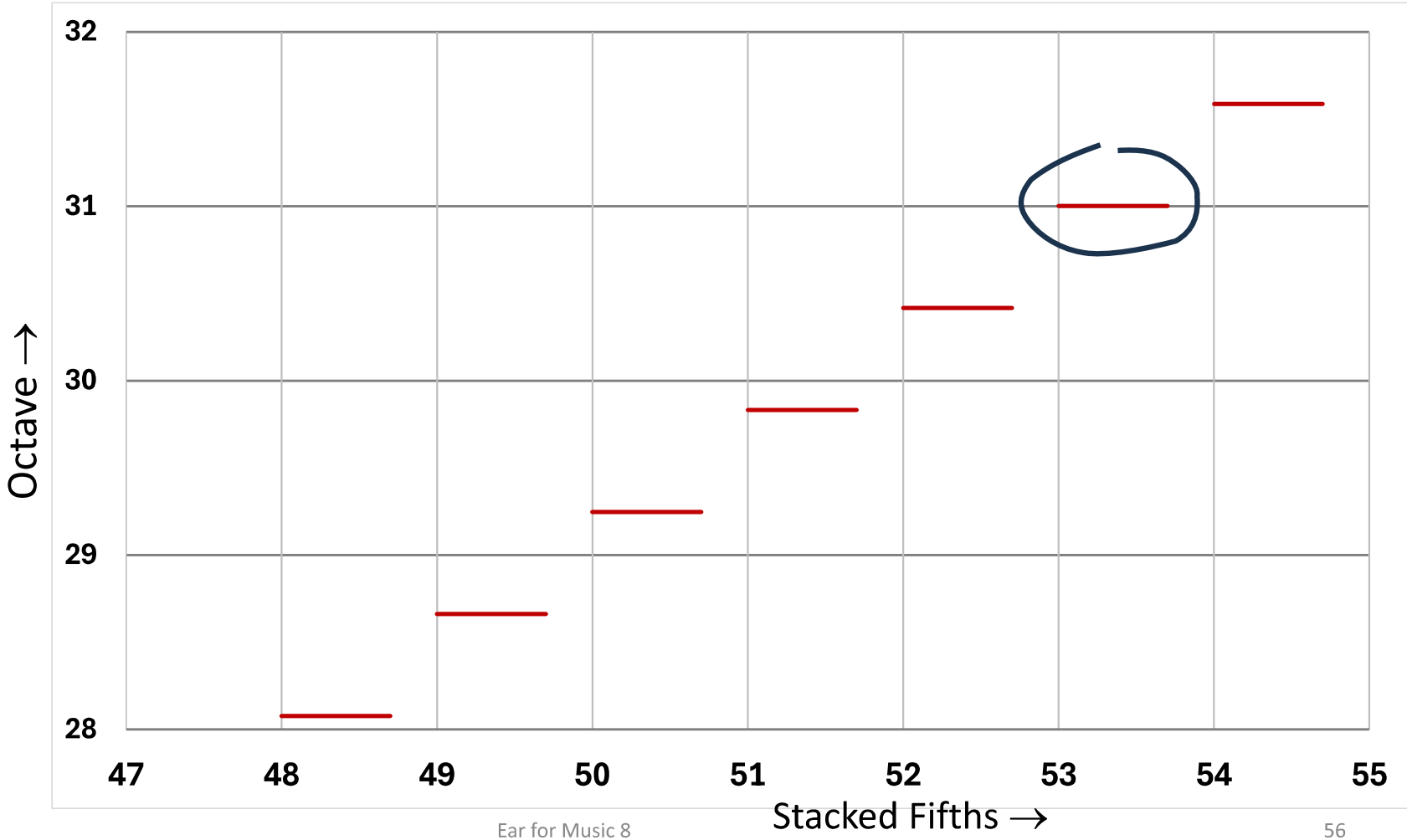


Pythagorean Scales:

Stacking "Fifths"

Keep on multiplying by 3/2 seeking an even better match to an Octave



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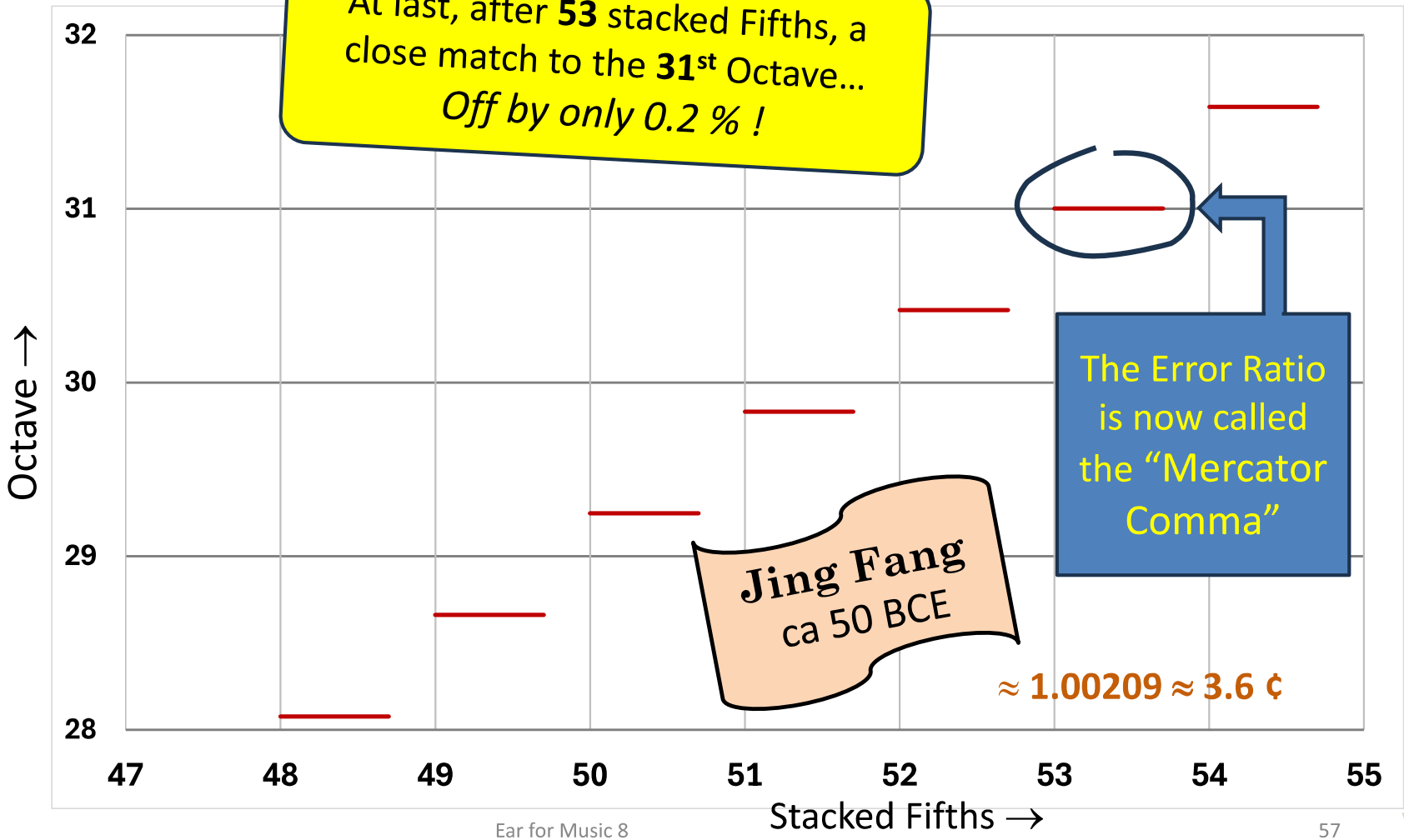
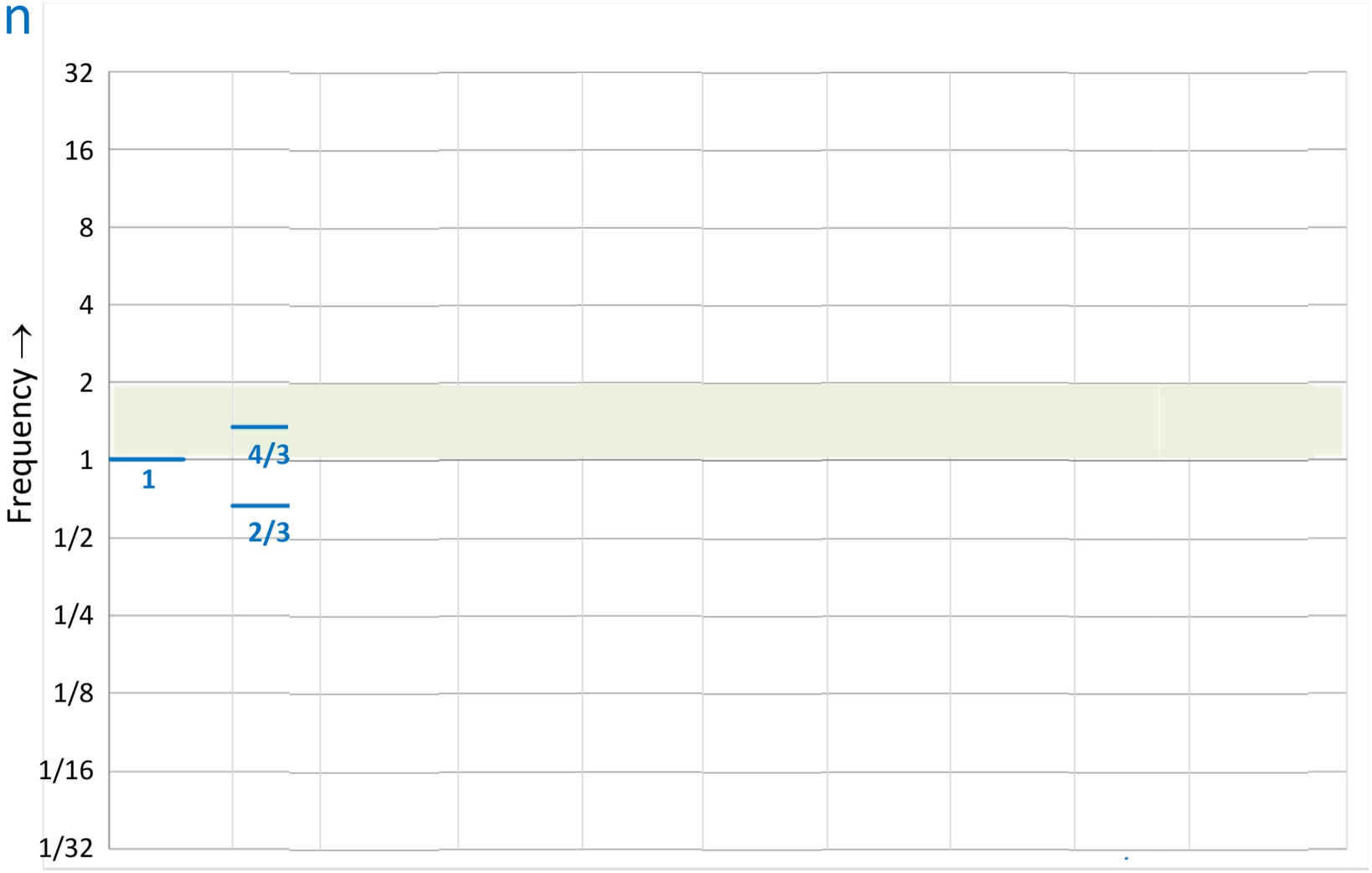


Pythagorean Scales:

Stacking "Fifths"

also go down by Fifths – dividing repeatedly by 3/2



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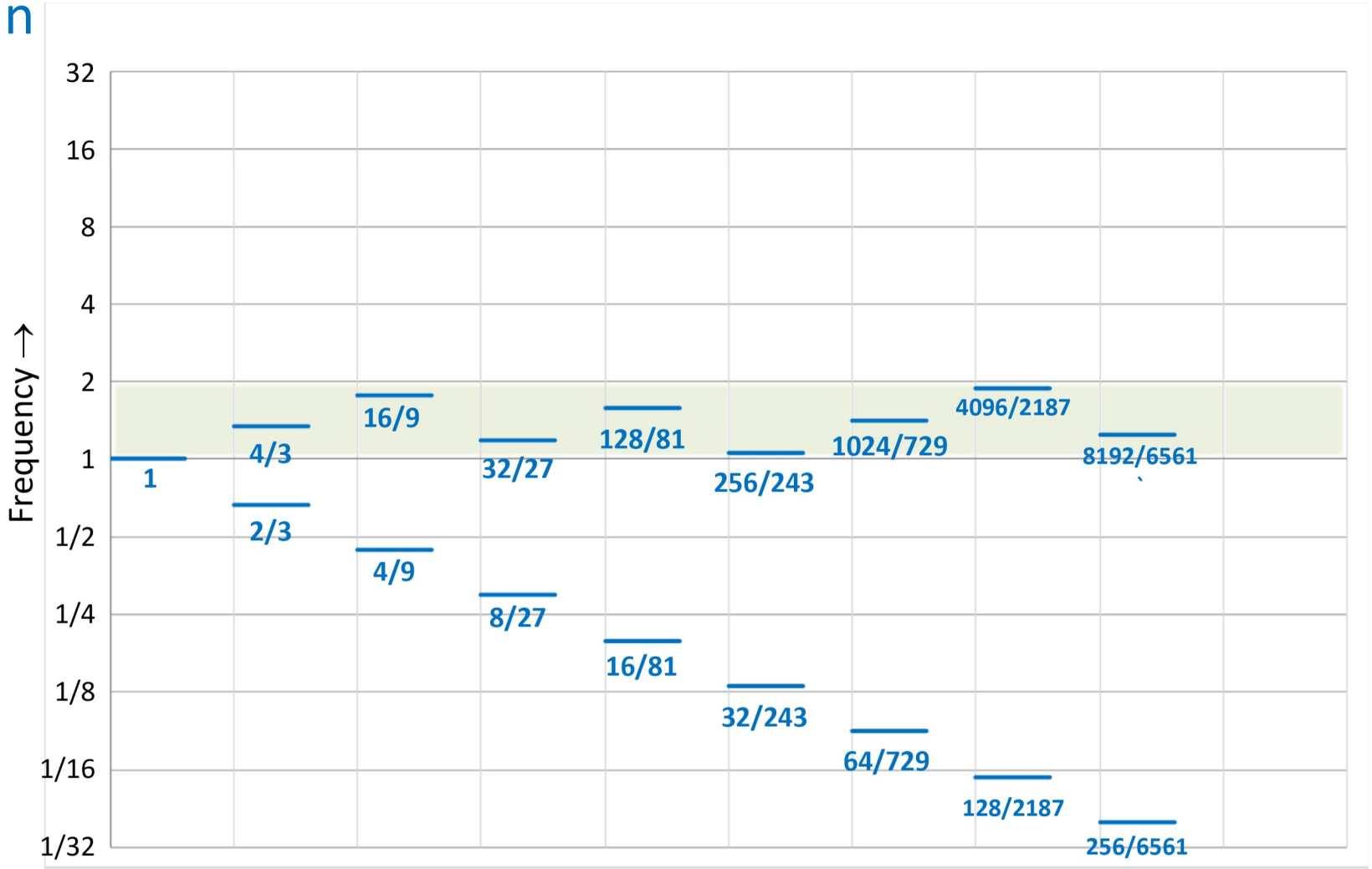

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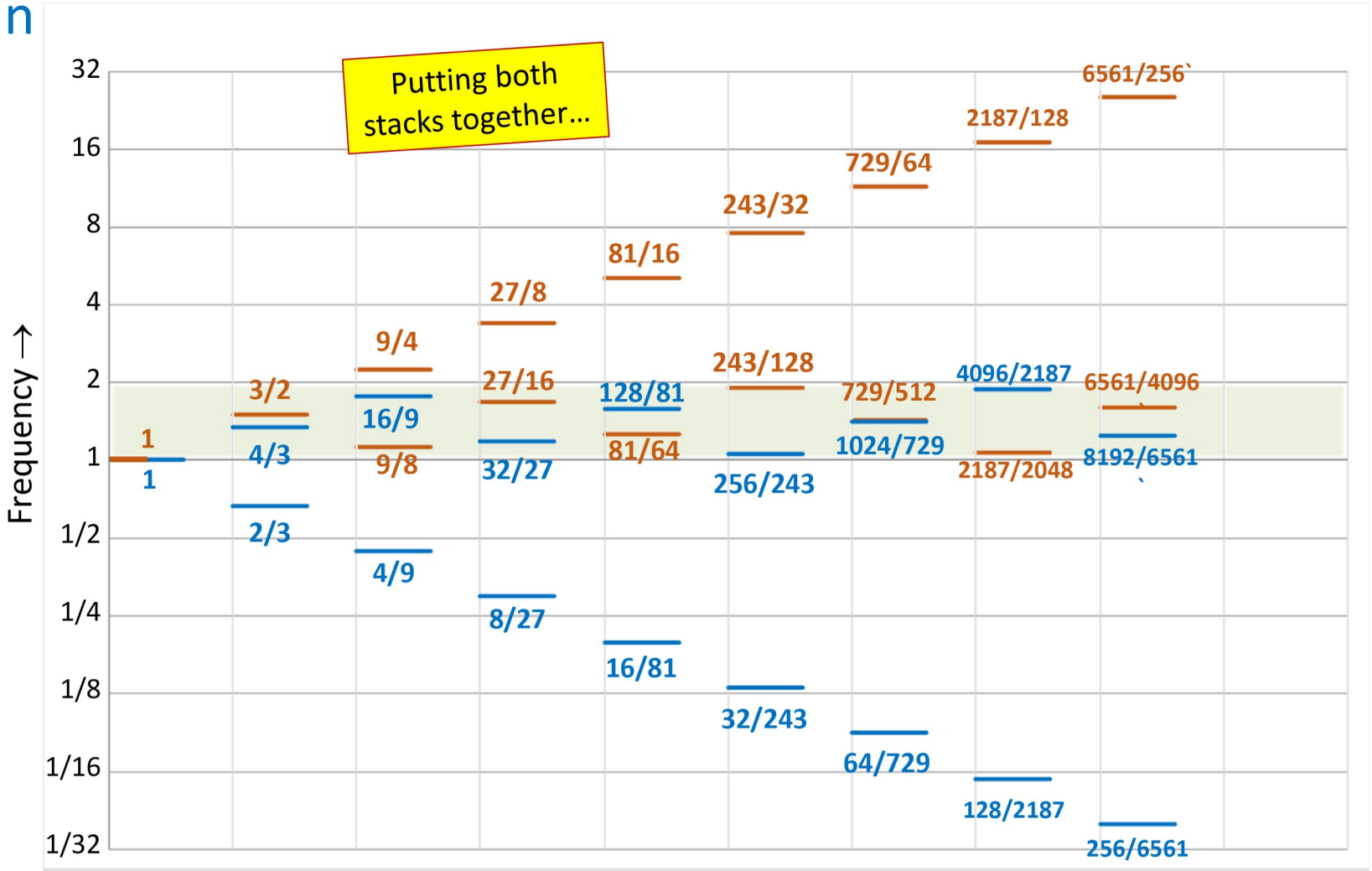

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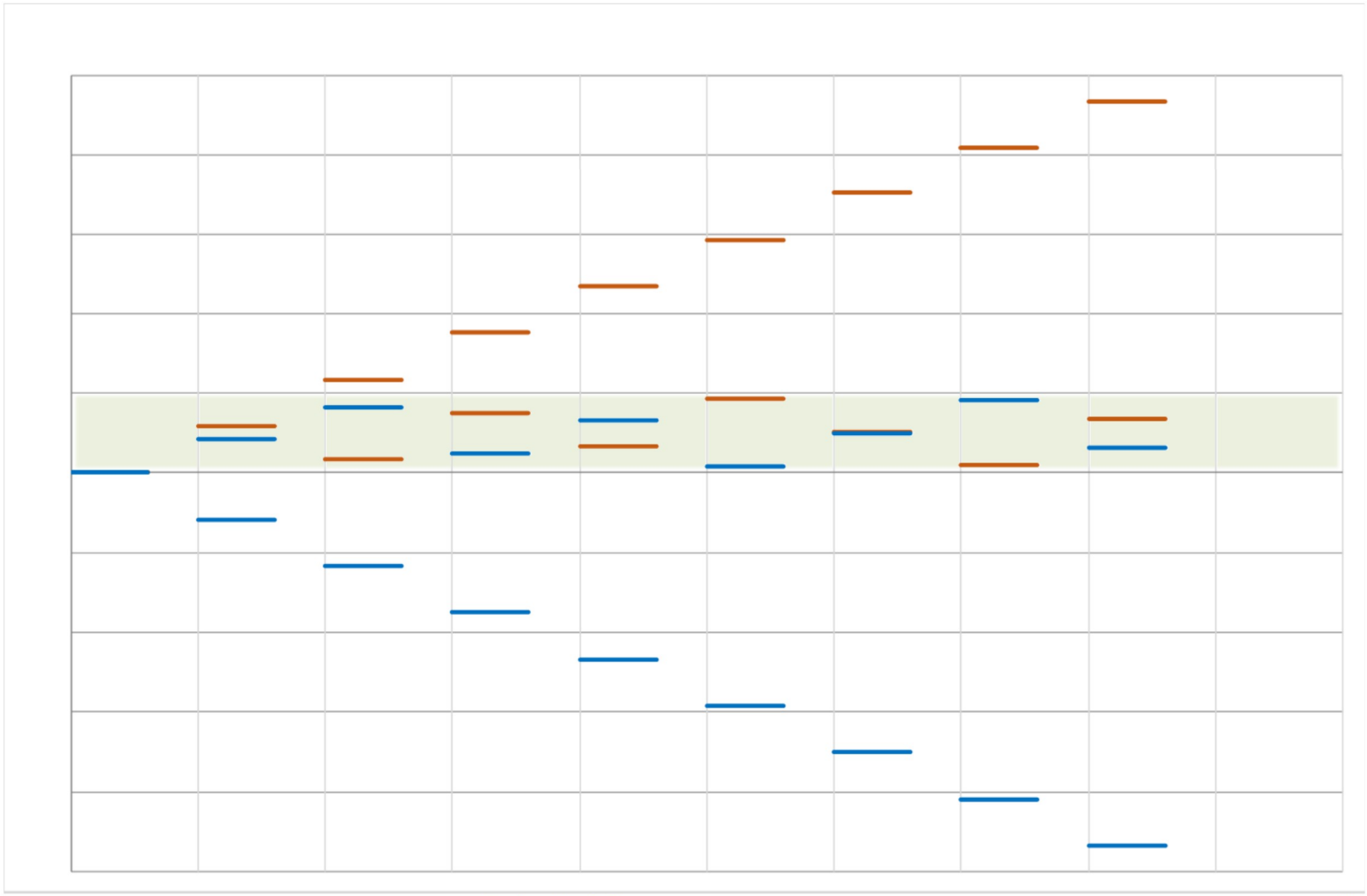

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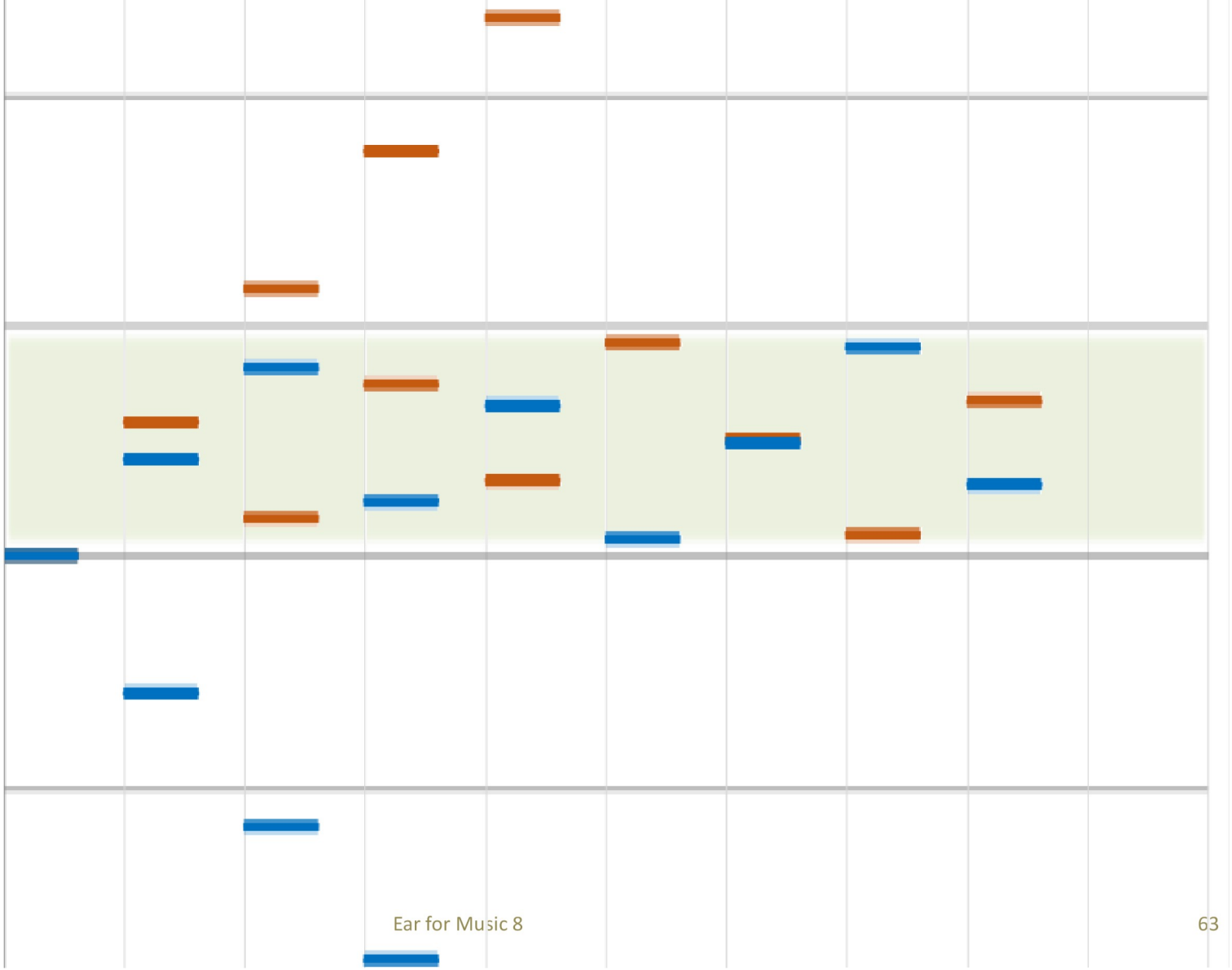

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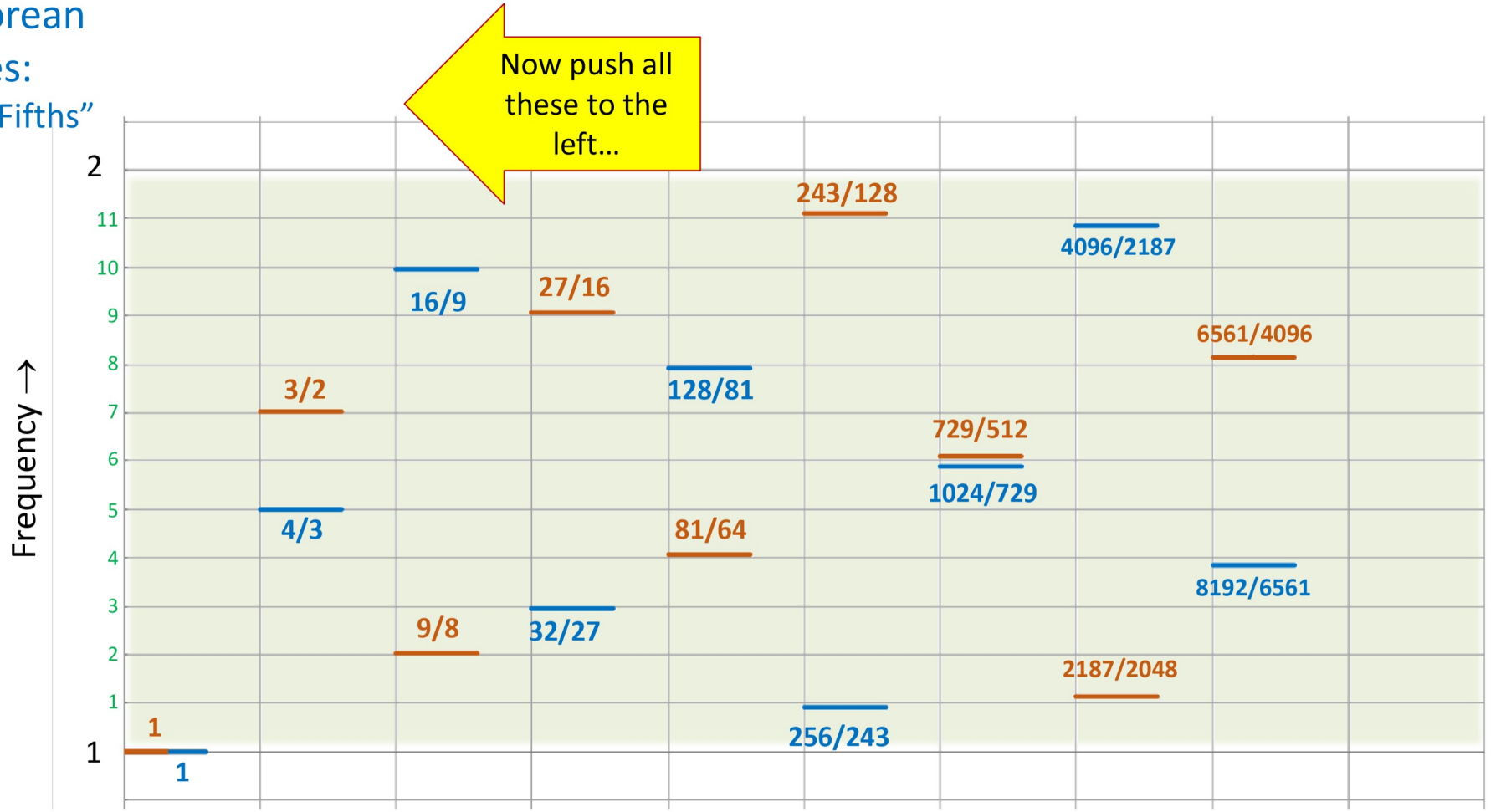
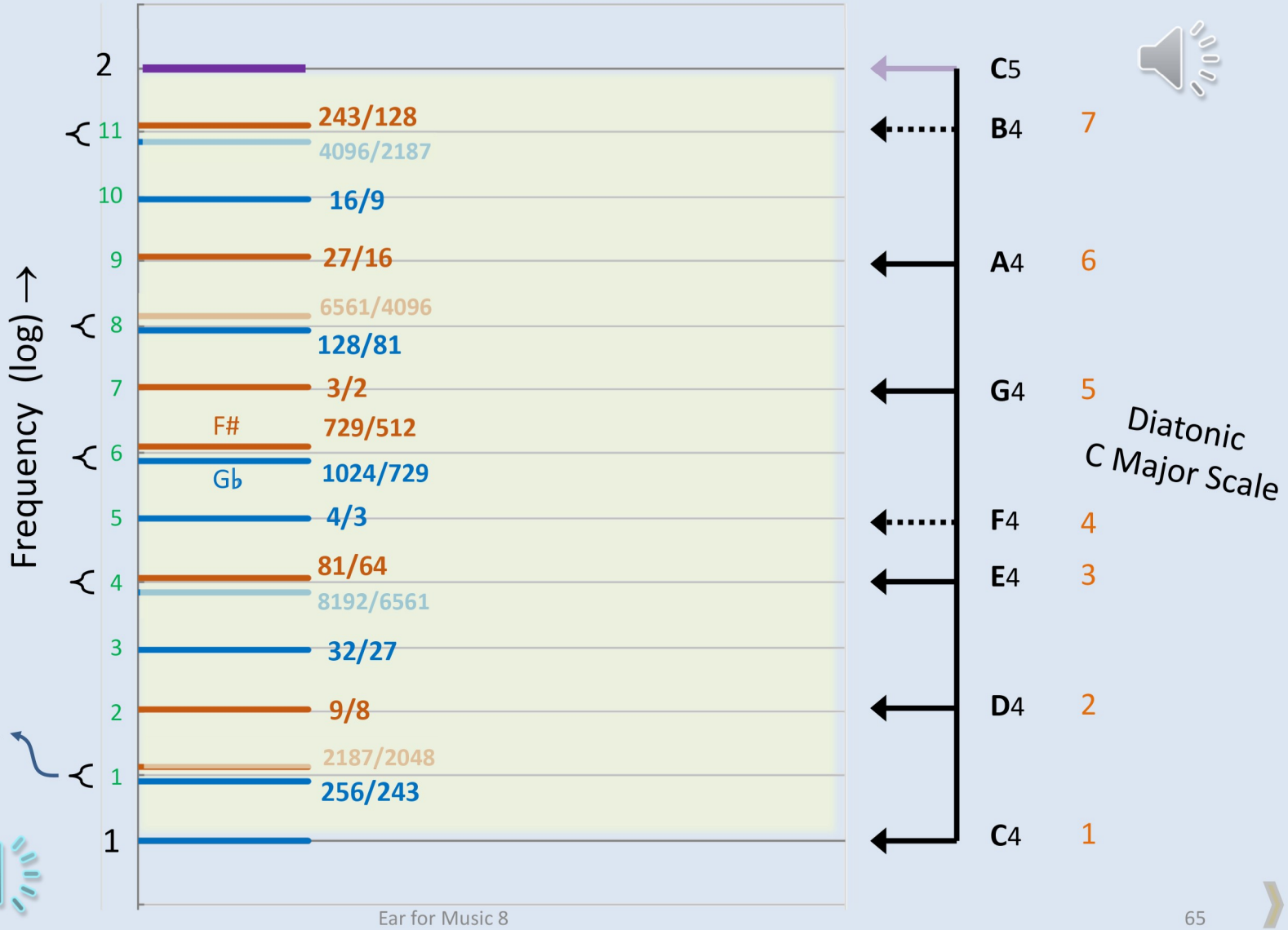


The Pythagorean Scale

[used until ~1600 CE]



The Pythagorean Comma (Euclid)

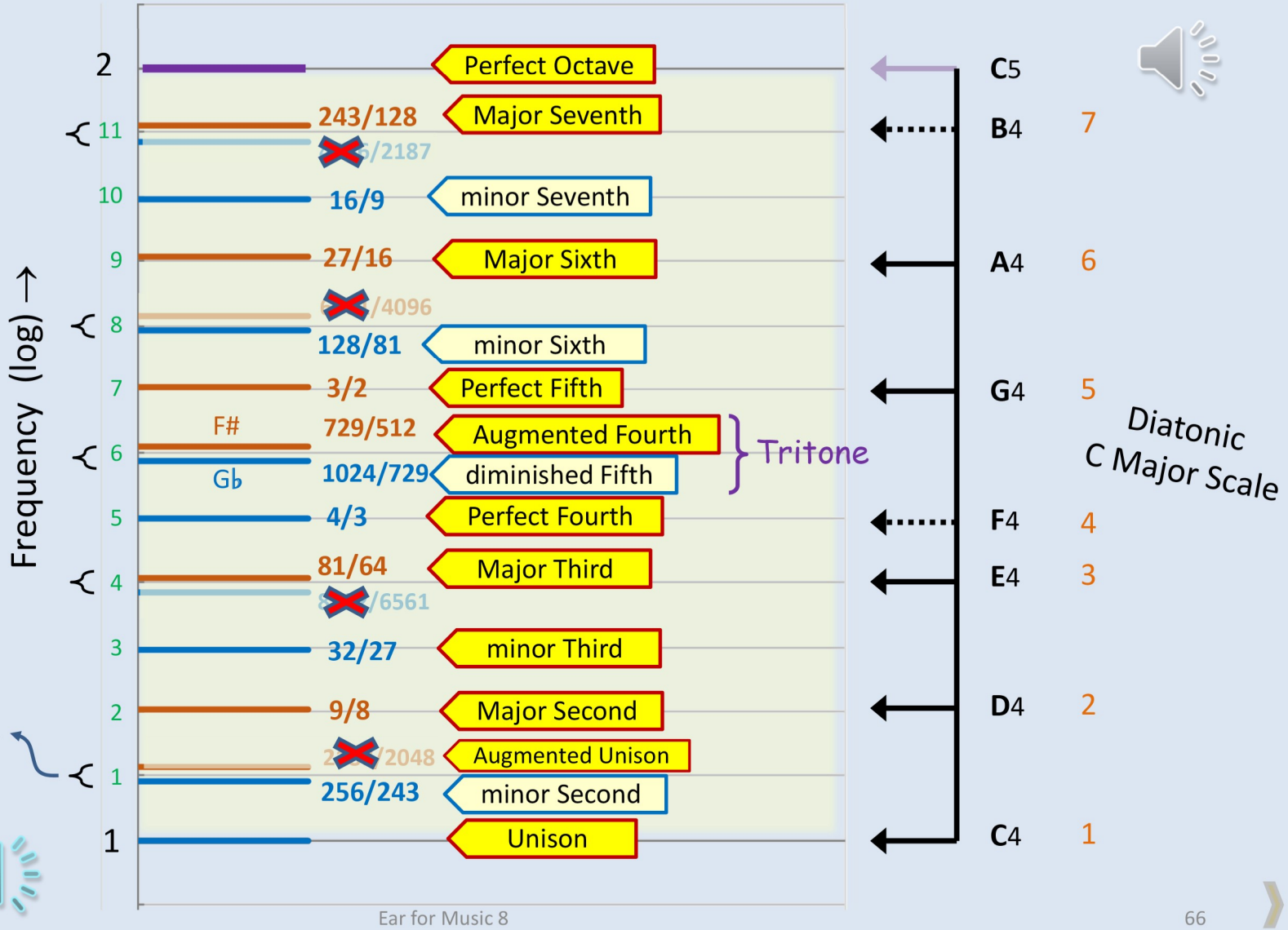
$$\frac{531441}{524288} \approx 1.01364\ldots$$

≈ 23.46 cents

The Pythagorean Scale

[used until ~1600 CE]

Arbitrarily eliminate some redundant frequencies



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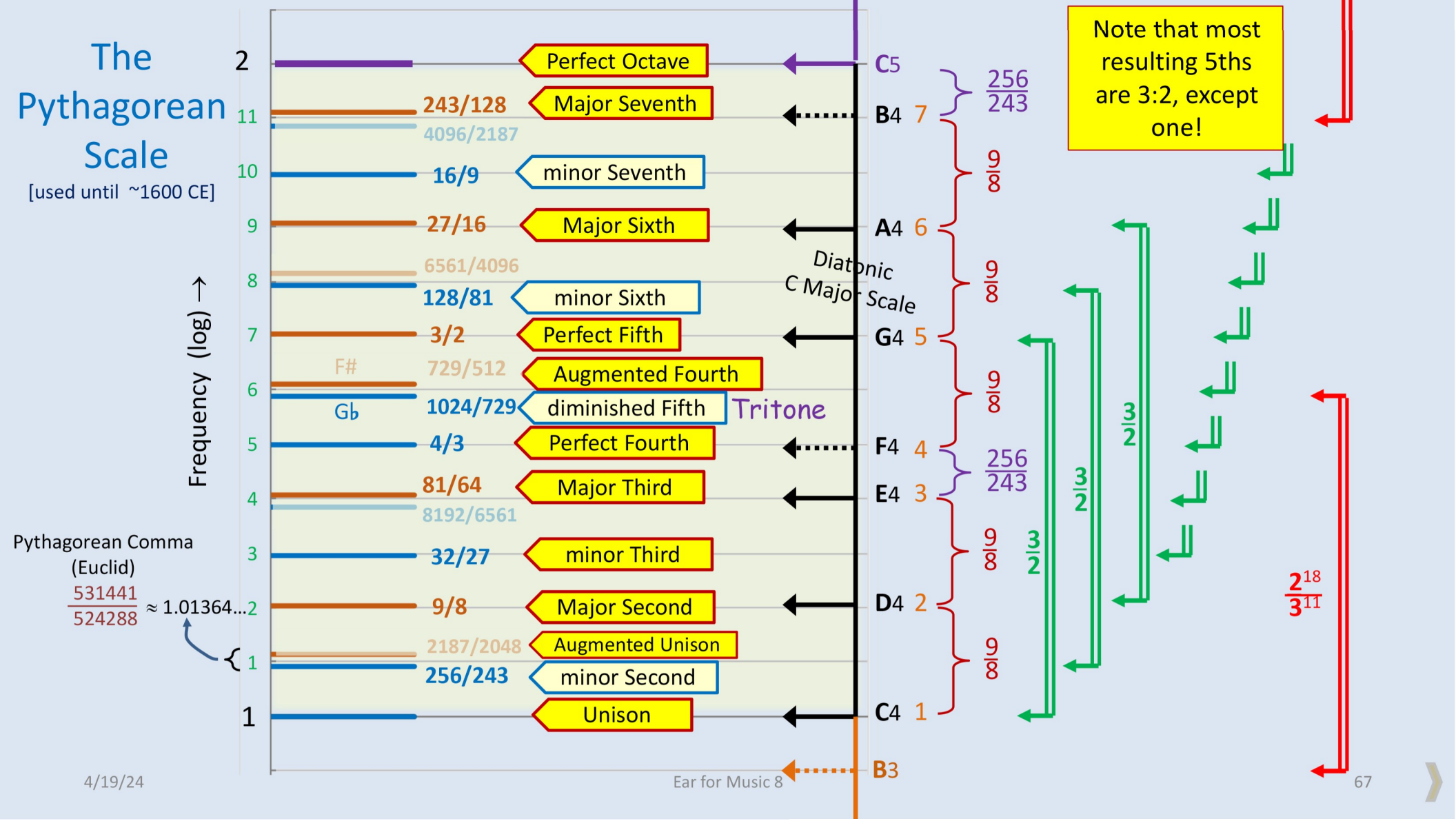

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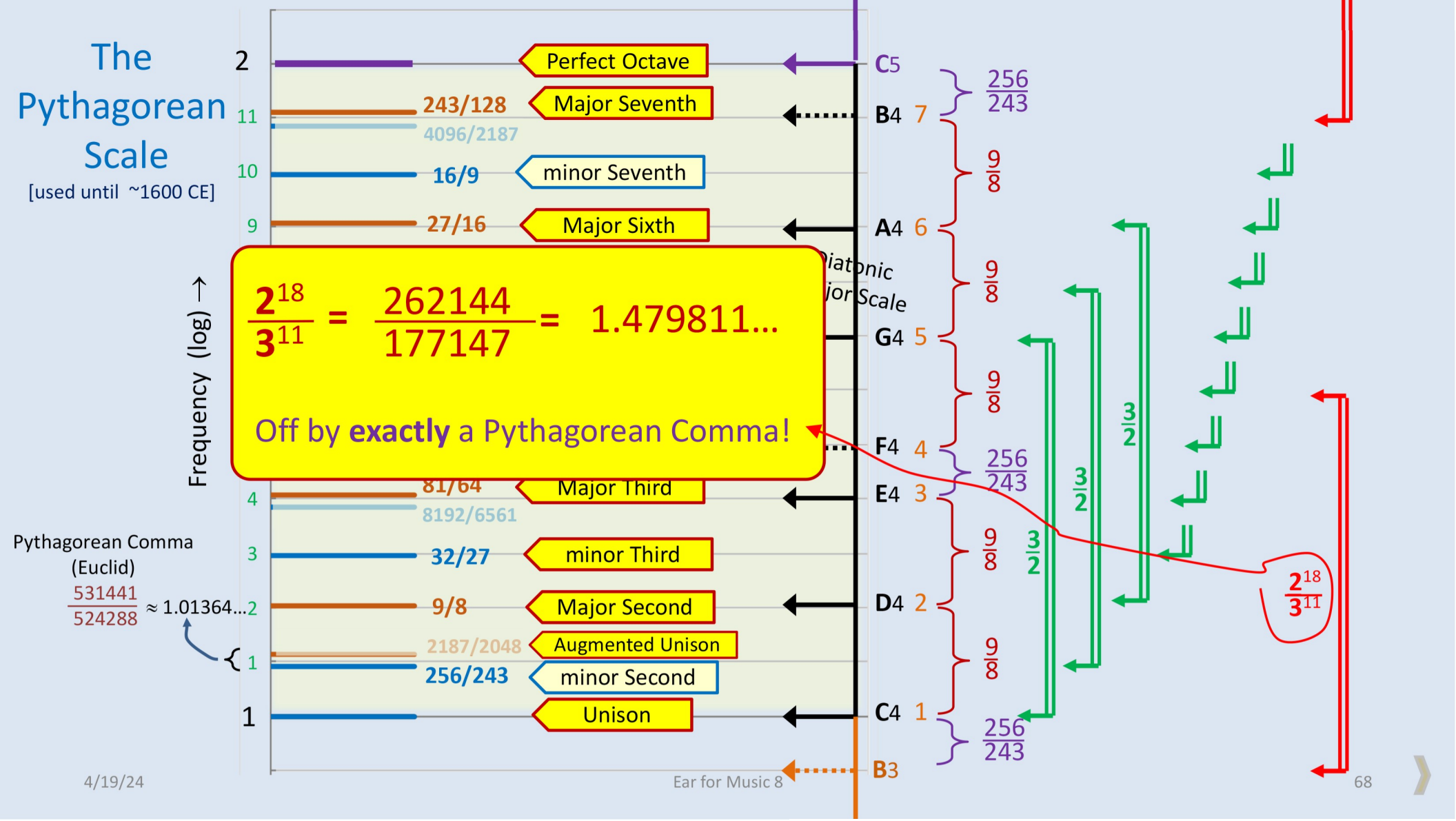


The Pythagorean Scale

[used until ~1600 CE]

$\frac{2^{18}}{3^{11}} =$

Off by

Pythagorean Comma (Euclid)

$\frac{531441}{524288} \approx 1.01364\ldots$

Frequency (log) →

2 — Perfect Octave — C5

11

10

9

4

3

2

1

256/243 — minor Second

1 — Unison — C4

B3

256

1

$\frac{256}{243}$

$\frac{3}{2}$

$\frac{3}{2}$

$\frac{3}{2}$

$\frac{2^{18}}{3^{11}}$

The Pythagorean Scale

[used until ~1600 CE]

Can you hear the Wolf Interval in these Fifths?

(as played one by one)

Pythagorean Comma (Euclid)

$\frac{531441}{524288} \approx 1.01364\ldots$

2 11 10 9 8 4 3 2 1 1

ifect Octave — C5

ajor Seventh — B4 7

nor Seventh

Major Sixth — A4 6

128/81 minor Sixth

3/2 Perfect Fifth — G4 5

29/512 Augmented Fourth

024/729 diminished Fifth — Tritone

3 Perfect Fourth — F4 4

81/64 Major Third — E4 3

8192/6561

32/27 minor Third

9/8 Major Second — D4 2

2187/2048 Augmented Unison

256/243 minor Second

Unison — C4 1

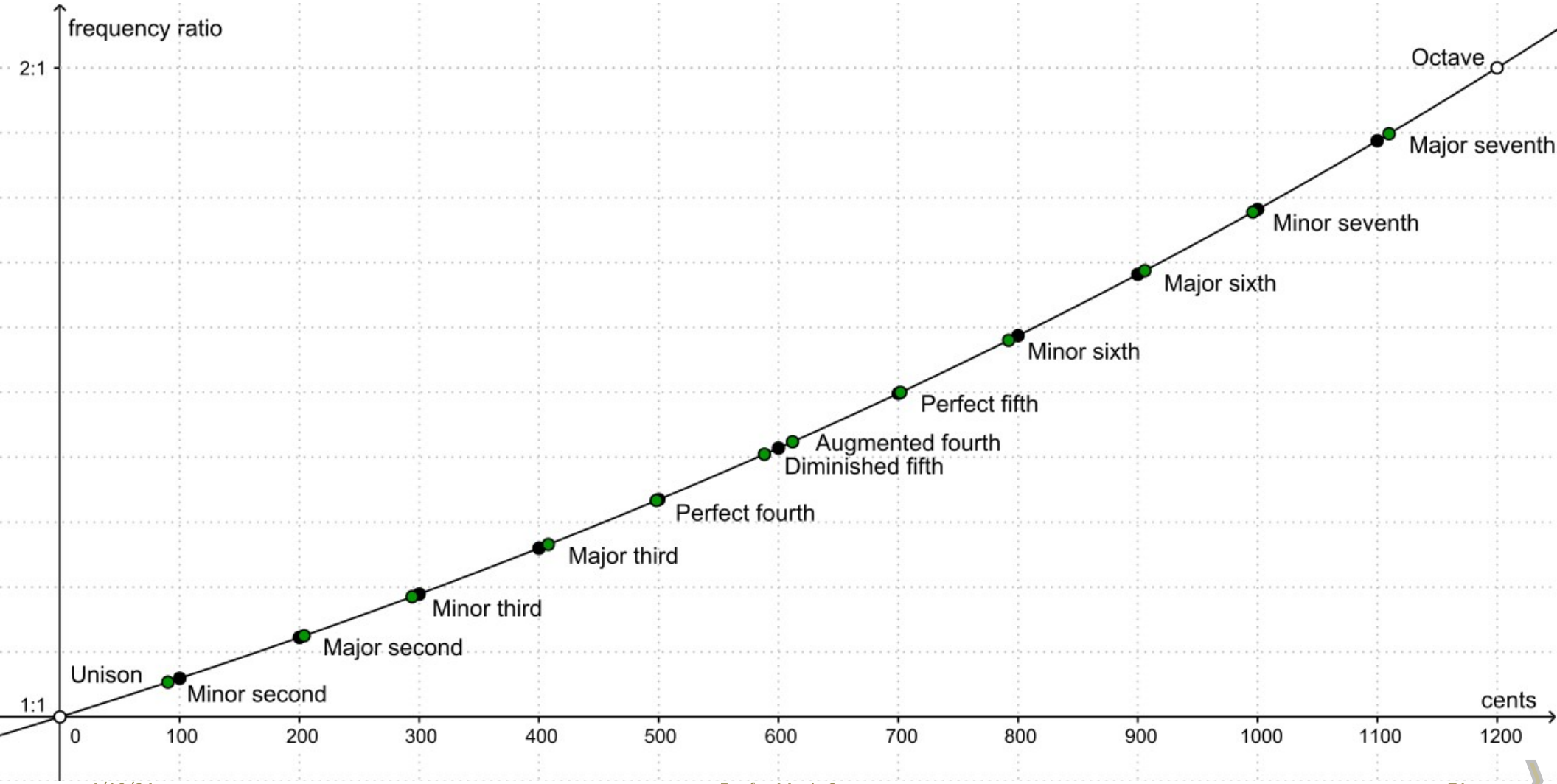
B3

Diatonic C Major Scale

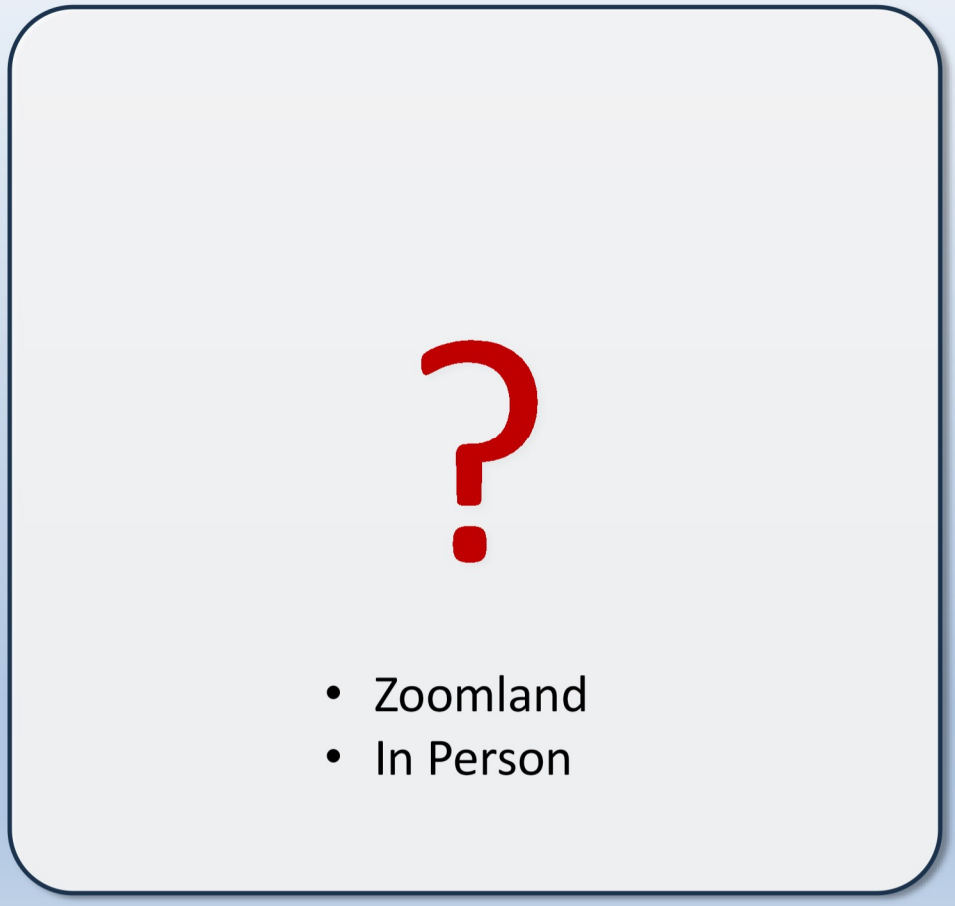
$\frac{256}{243}$ $\frac{9}{8}$ $\frac{9}{8}$ $\frac{9}{8}$ $\frac{256}{243}$ $\frac{9}{8}$ $\frac{9}{8}$ $\frac{256}{243}$

$\frac{3}{2}$ $\frac{3}{2}$ $\frac{3}{2}$

$\frac{2^{18}}{3^{11}}$

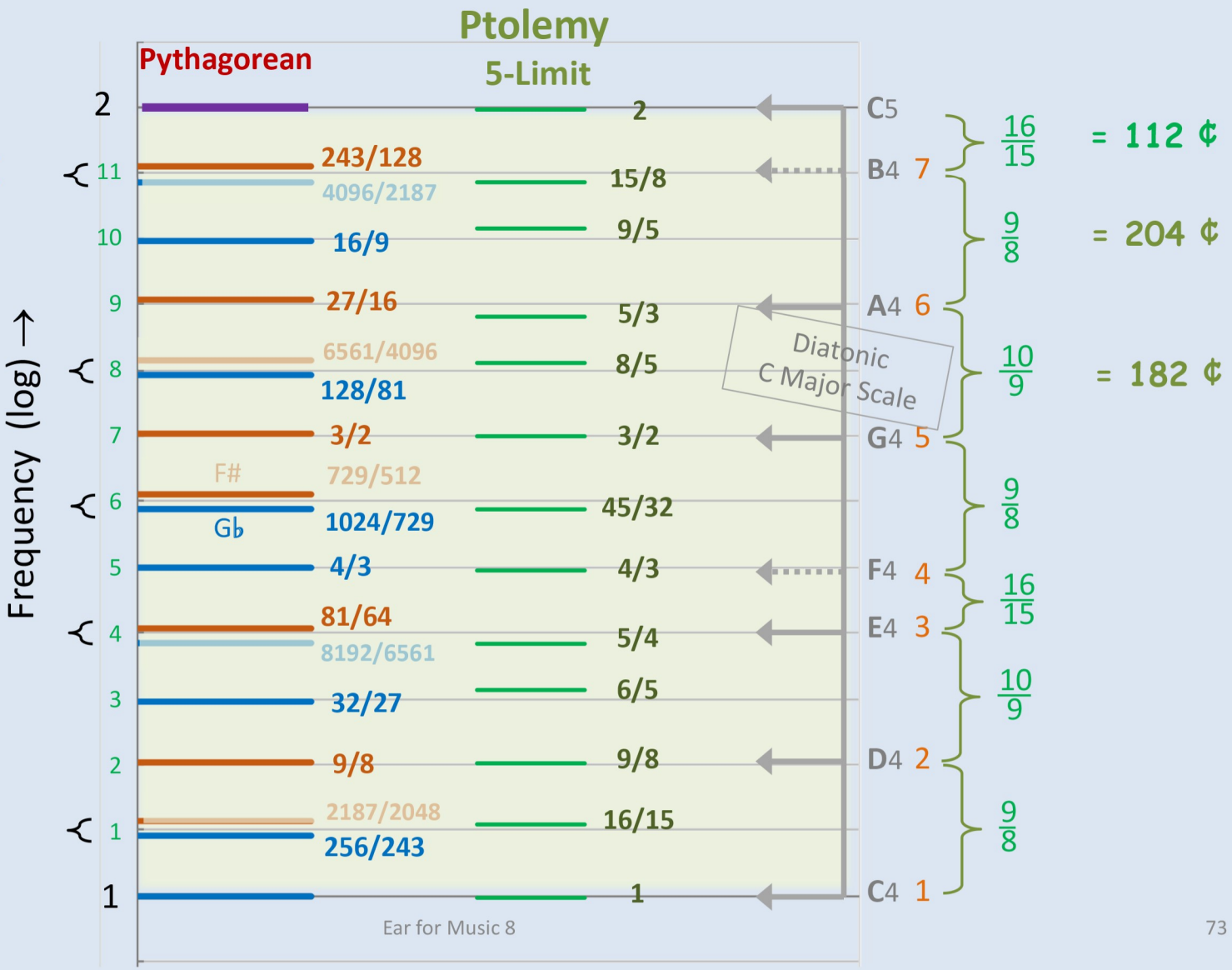

frequency ratio
2:1
1:1
Octave
Major seventh
Minor seventh
Major sixth
Minor sixth
Perfect fifth
Augmented fourth
Diminished fifth
Perfect fourth
Major third
Minor third
Major second
Unison
Minor second
cents
0
100
200
300
400
500
600
700
800
900
1000
1100
1200

Question Time



Ptolemy's "Intense 5-Limit Just Scale"

Built similarly to Pythagorean, but using not just 2 and 3 as factors, but allowing 5,3 and 2 in numerators and denominators.



A Few of Many Tuning Schemes

1. The Equal Tempered Chromatic Scale (our "Mother Scale")
   - Notes equally spaced on log scale (equal ratios of $\sqrt[12]{2} \approx 1.06$)
2. Pythagorean Tuning
   - Based on "fifths" -- powers of 3 and 2. All ratios *rational* (integer ratios).
3. Just Tuning (5-limit) [*a.k.a.* Ptolemy Intense 5-Limit]
   - Similar to Pythagorean, but including powers of 5, 3 and 2 (integer ratios).
4. Meantone Temperament *(many types)*
   - Similar to Pythagorean, but based on quasi-fifth ratios slightly under 3:2
5. Well Temperaments *(many types)*
   - Complex adjustments to optimize certain types of music

Quid non-Ebrietas

The song that broke Pythagorean Tuning?

What cannot be achieved through inebriation?
It reveals secrets, bids hopes to be confirmed,
thrusts the inactive into battle,
lifts the burden from troubled minds,
teaches new skills.
Whom do brimming glasses not make eloquent?
Whom do they not free from the bonds of poverty?

Adrian Willaert
Flemish Composer
(1490 – 1562)


Quid non Ebrietas (reconstruction) **Adrian Willaert**
Andrew Hallock (2019)

Quid non ebrietas

Adrian Willaert

Adrian Willaert

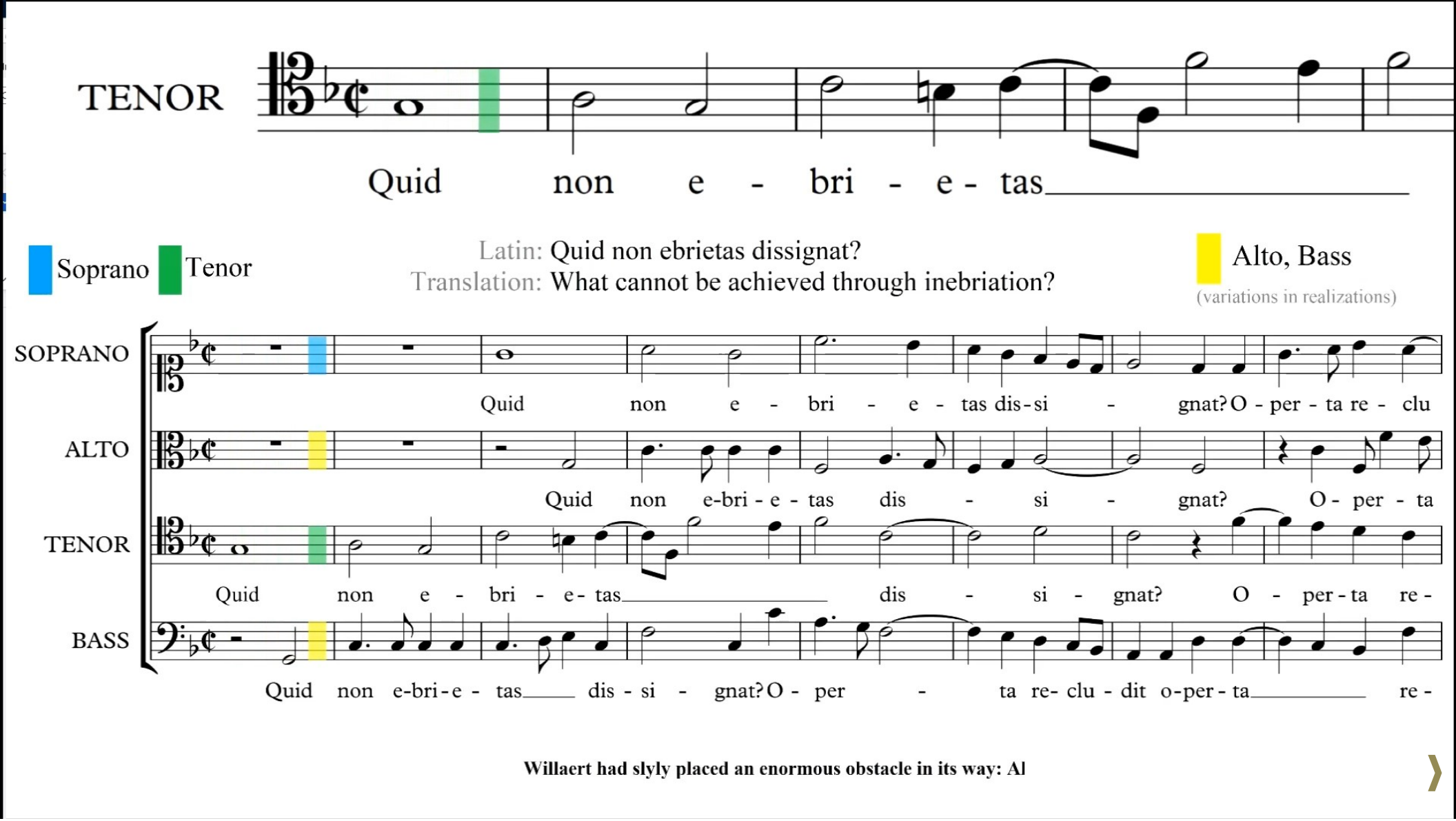
(c. 1490 – 7 December 1562)

Critics compared Quid non ebrietas with Archimedes' unsuccessful attempt to square the circle. One reason was the philosophical underpinning of his venture. After all, Pythagorian tuning was under attack. What's worse, it was being threatened by the ascendance of an ancient rival Aristoxenus. Willaert had joined the camp of the renegade philosopher whose third century B.C.E. musings on the possibility of an equal division of the octave had triggered Boethius's blustery dismissal of the idea. Besides, this music was just not easy. According to the composer and theorist Giovanni Spataro, a student of Ramos and choirmaster of Bologna's basilica, Quid non ebrietas was in fact performed by the singers of the papal chapel: "but not very successfully."

Willaert's piece was composed in the year Ferdinand Magellan first set sail, and the tenor in Quid non ebrietas moves through difficult musical straits like an explorer conquering uncharted regions. However, Willaert's map, unlike those of Columbus or Magellan, was unfailingly clear. His music reflected not so much a venture into the unknown as it did a composer boldly staking a position.

It would succeed flawlessly, however, with a radical tuning (at the time) called equal temperament.

Excerpt from Temperament by Stuart Isacoff



Willaert had slyly placed an enormous obstacle in its way: Al

Comparison of Alternative Tuning Schemes and Temperaments

12 Notes per Octave

Log Frequency Scale

Notes labeled with ratios to base frequency

Equal Temperament	Pythagorean Tuning	Just Tuning (5-limit)	Meantone (1/4 Comma)	Well Temper Werckmeister-I
2	2	2	2	2
1.888	243/128	15/8	1.8694	1.879
1.782	16/9	9/5	1.789	1.778
1.682	27/16	5/3	1.672	1.670
1.587	128/81	8/5	1.600	1.580
1.498	3/2	3/2	1.495	1.495
1.414	729/512	45/32	1.398	1.404
1.335	4/3	4/3	1.338	1.333
1.260	81/64	5/4	1.250	1.253
1.189	32/27	6/5	1.196	1.185
1.122	9/8	9/8	1.118	1.117
$\sqrt[12]{2}$ = 1.059	256/243	16/15	1.070	1.053
1	1	1	1	1

Comparison of Alternative Tuning Schemes and Temperaments

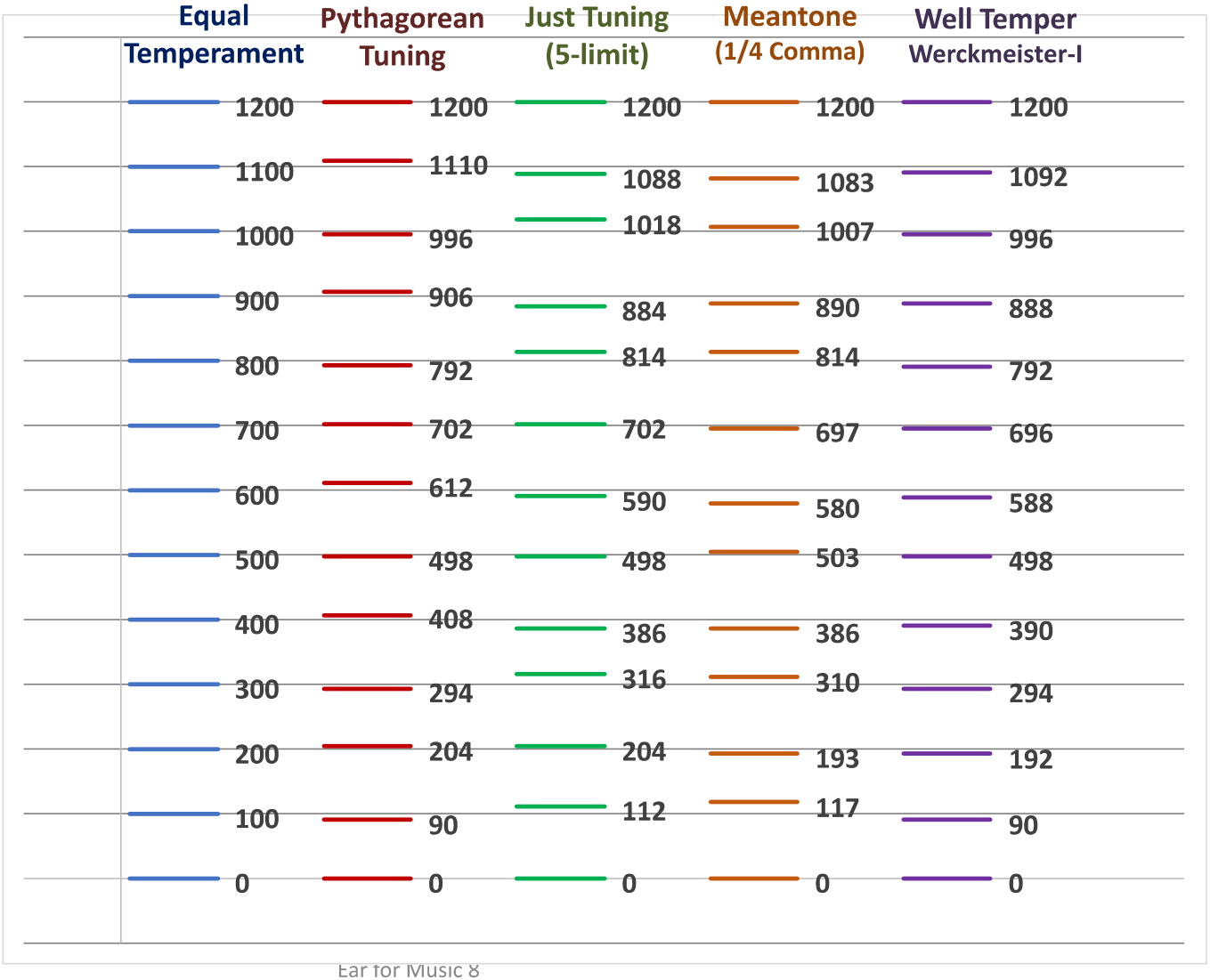
12 Notes per Octave

Log Frequency Scale

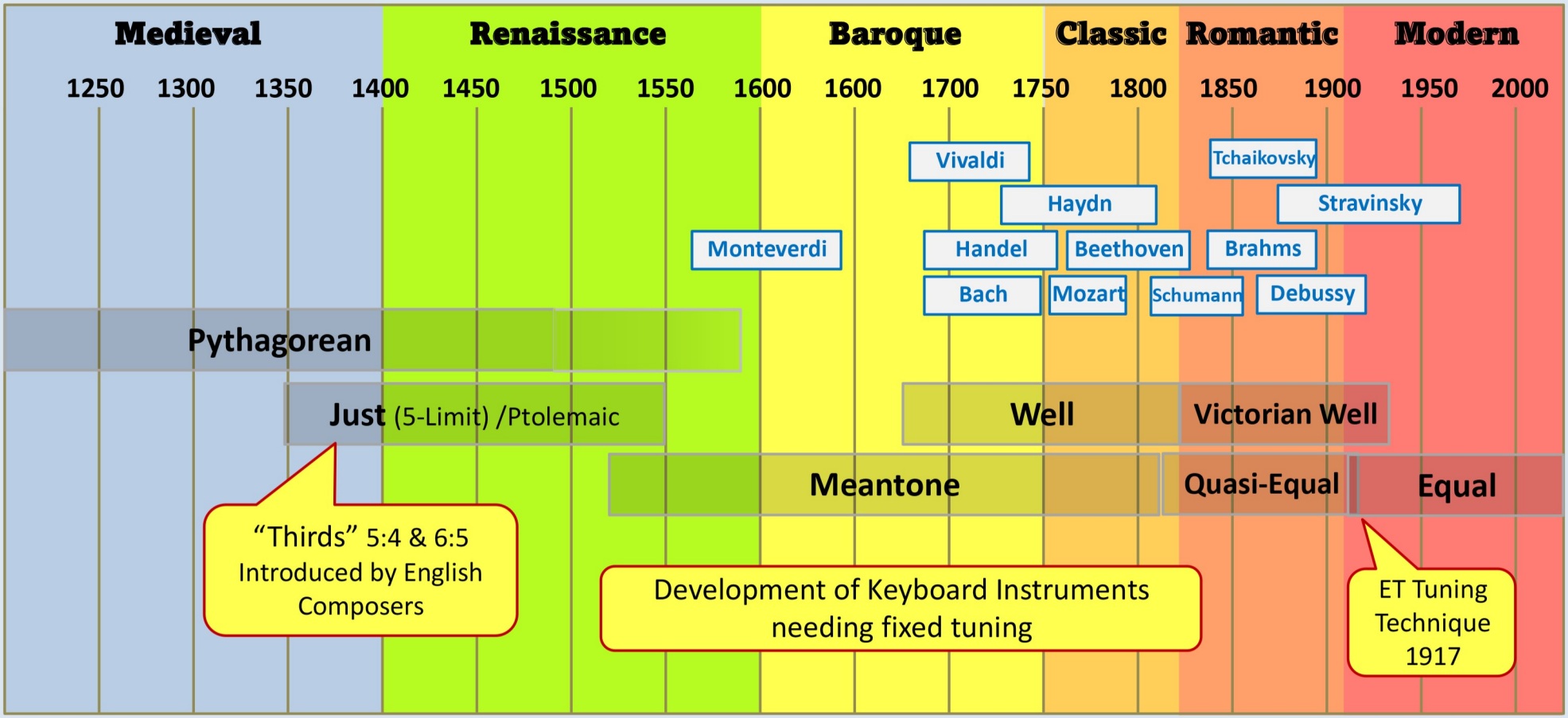
Notes labeled with frequencies in Cents above base frequency

100 cents = ET note interval

(1200 cents = 1 octave)



Intonation and Temperament Timeline in Western Music



Split Key Harpsichord: 19 Notes per Octave

No Compromise – get any ratio you need. Several choices for some notes.

Christopher Stembridge on CD *Consonanze Stravaganti* (2000)

Modern reproduction of 1631 Italian Faber Instrument

Denzil Wraight

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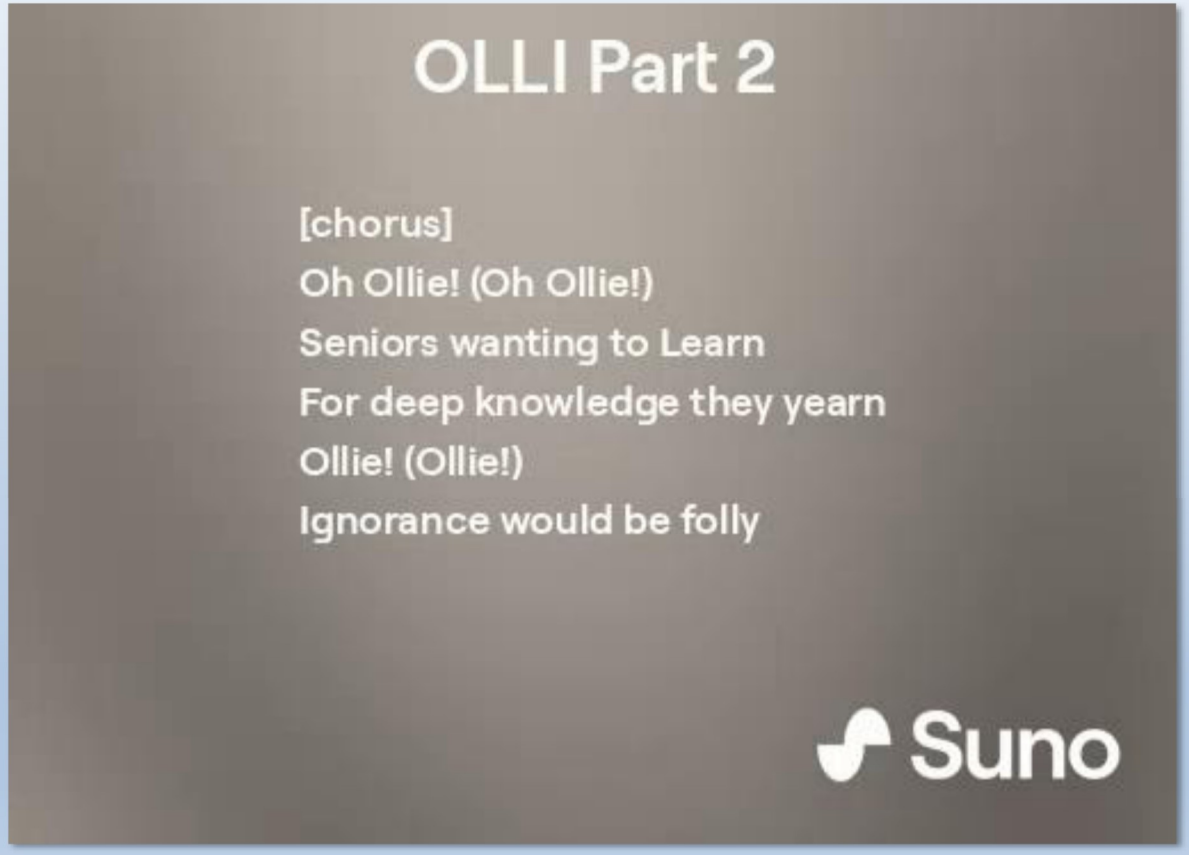

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Suno.com

Thanks for joining me on this musical inquisition!