



Sound of Music

How It Works

Session 8B
Harmony and Dissonance



OLLI at Illinois
Spring 2020

D. H. Tracy

To Request a link to a Powerpoint Version with Sound and Animations

- Send an email to OLLI_Tracy@outlook.com
 - Say whether you want “Sound of Music 8 – Notation”
or “Sound of Music 8 – Harmony”
or both.
- Note that you will need a recent version of Microsoft Powerpoint on your computer to view these pptx files.

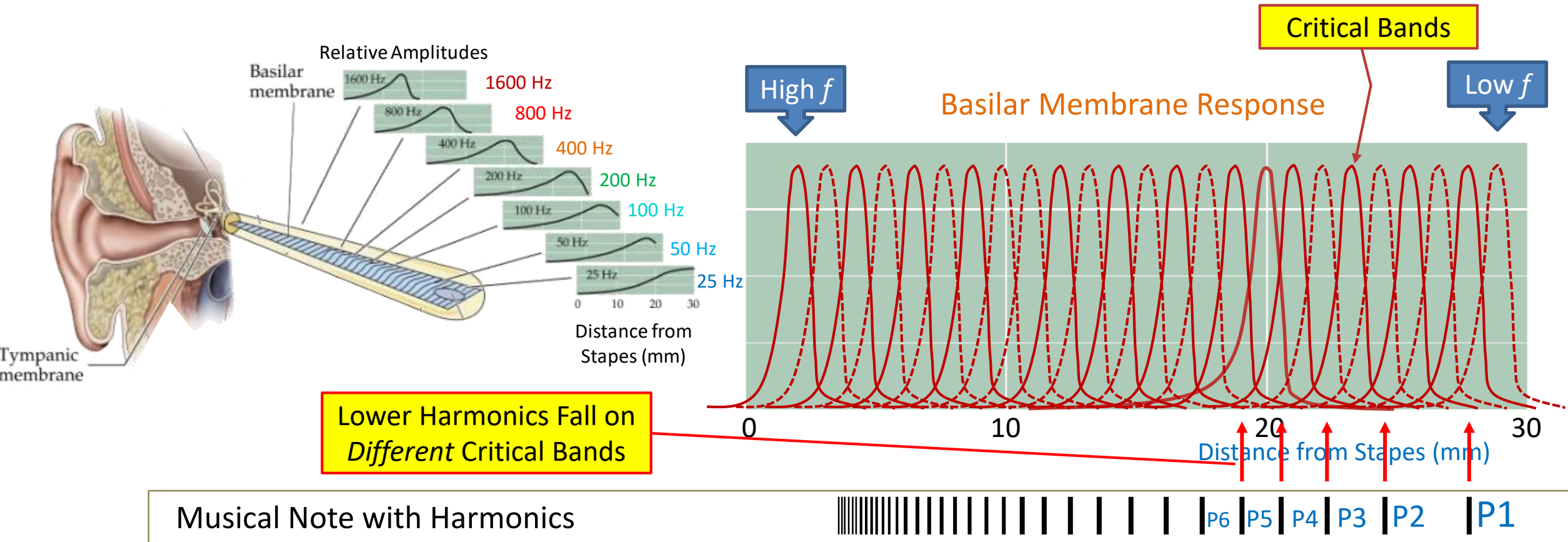
Course Outline



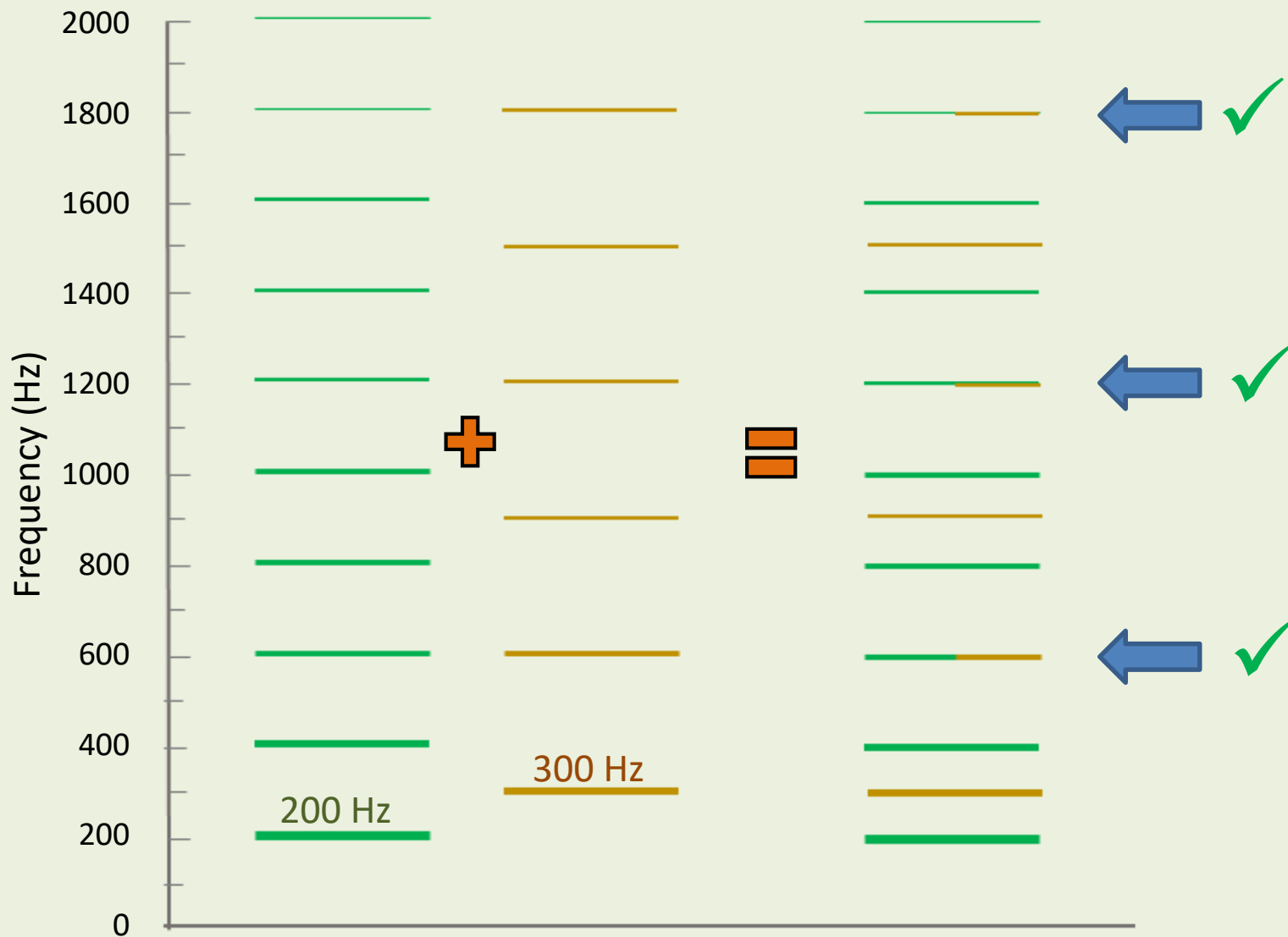
1. Building Blocks: Some basic concepts
2. Resonance: Building Sounds
3. Hearing and the Ear
4. Musical Scales
5. Musical Instruments
6. More Musical Instruments
7. Singing
- 8. Music Notation; Harmony and Dissonance**

Consonance and Dissonance

It's the Basilar Membrane, As We Know

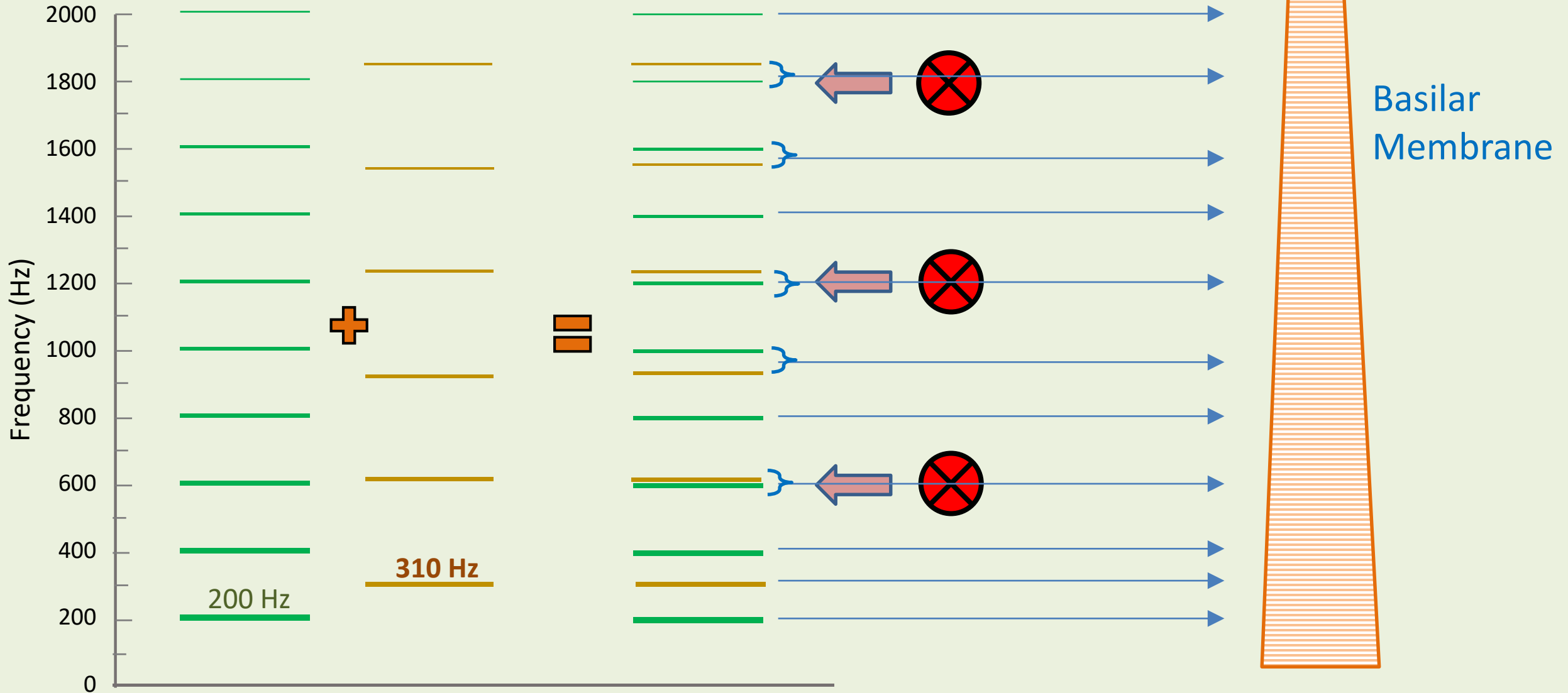


Remember The “Power Chord” ?

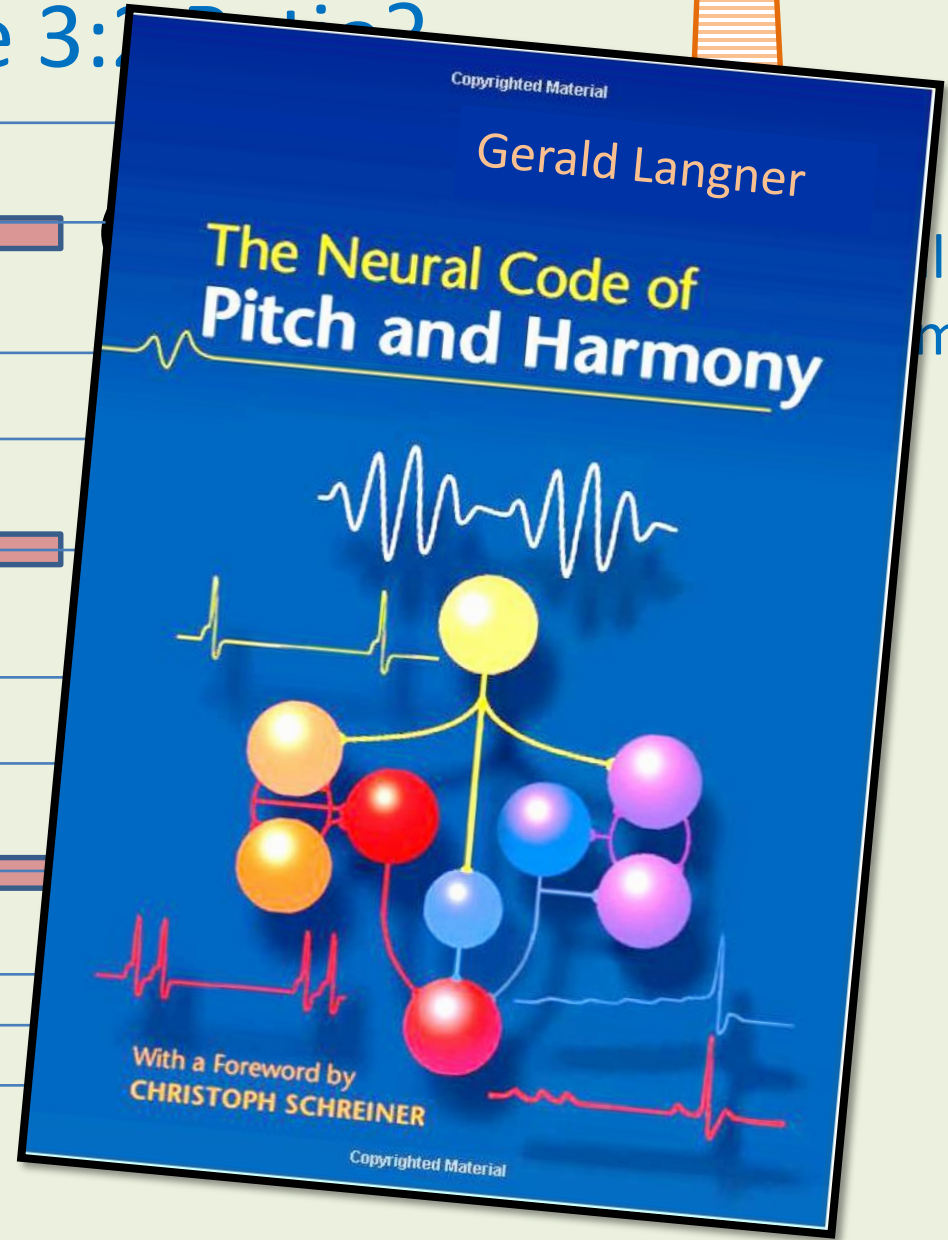
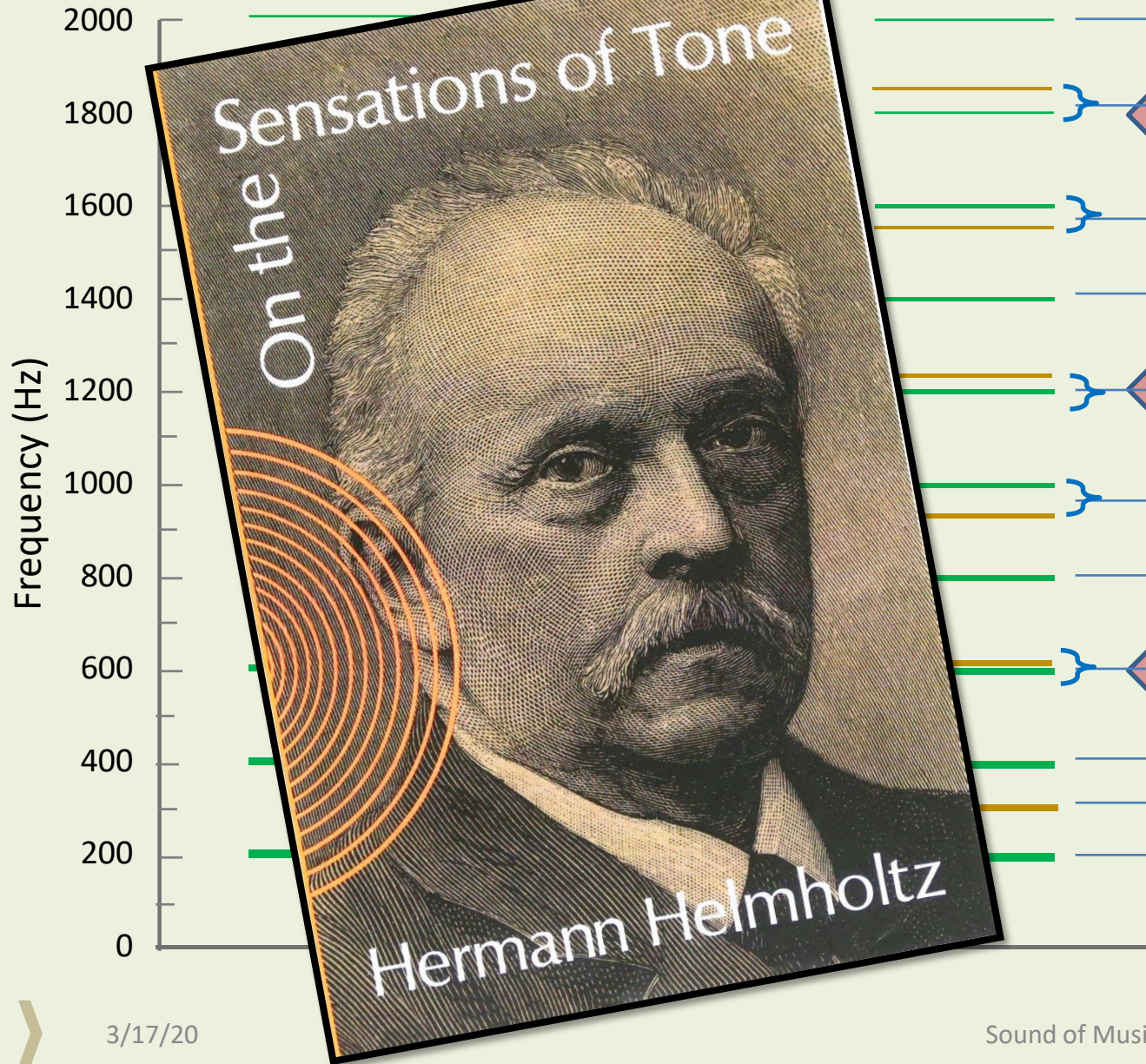


- Combination of 2 notes played together
- **3:2** Frequency Ratio
- Also called “Fifth Chord” or “Open Fifth Chord”

What If We Corrupt the 3:2 Ratio?



What If We Corrupt the 3:2 Ratio?

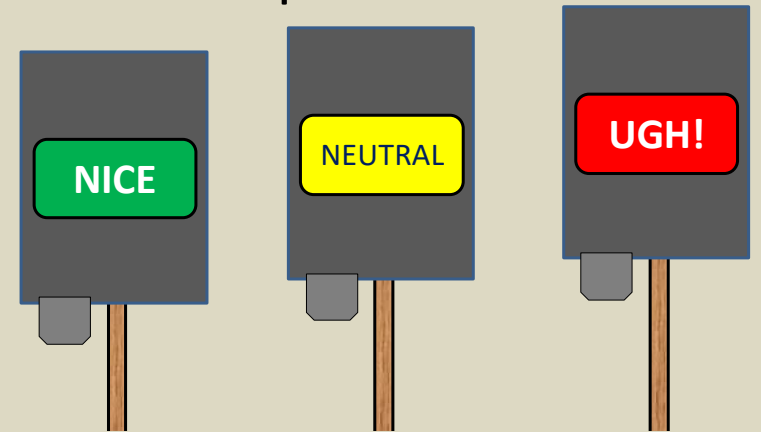


lar
mbrane

Consonance Experiment



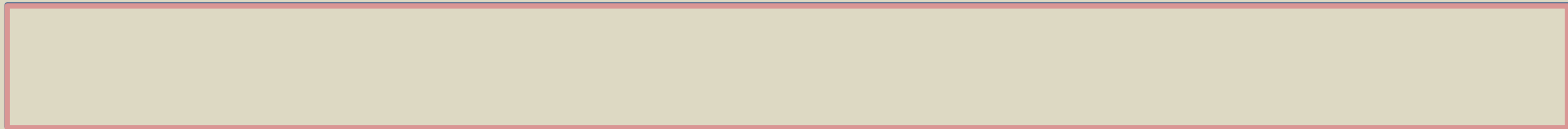
- You will hear 2 complex tones played simultaneously
- Relax and Judge the *Pleasantness* of the pair
 - **Green** = Quite Pleasant
 - **Yellow** = So-so
 - **Red** = Less Pleasant



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



3x



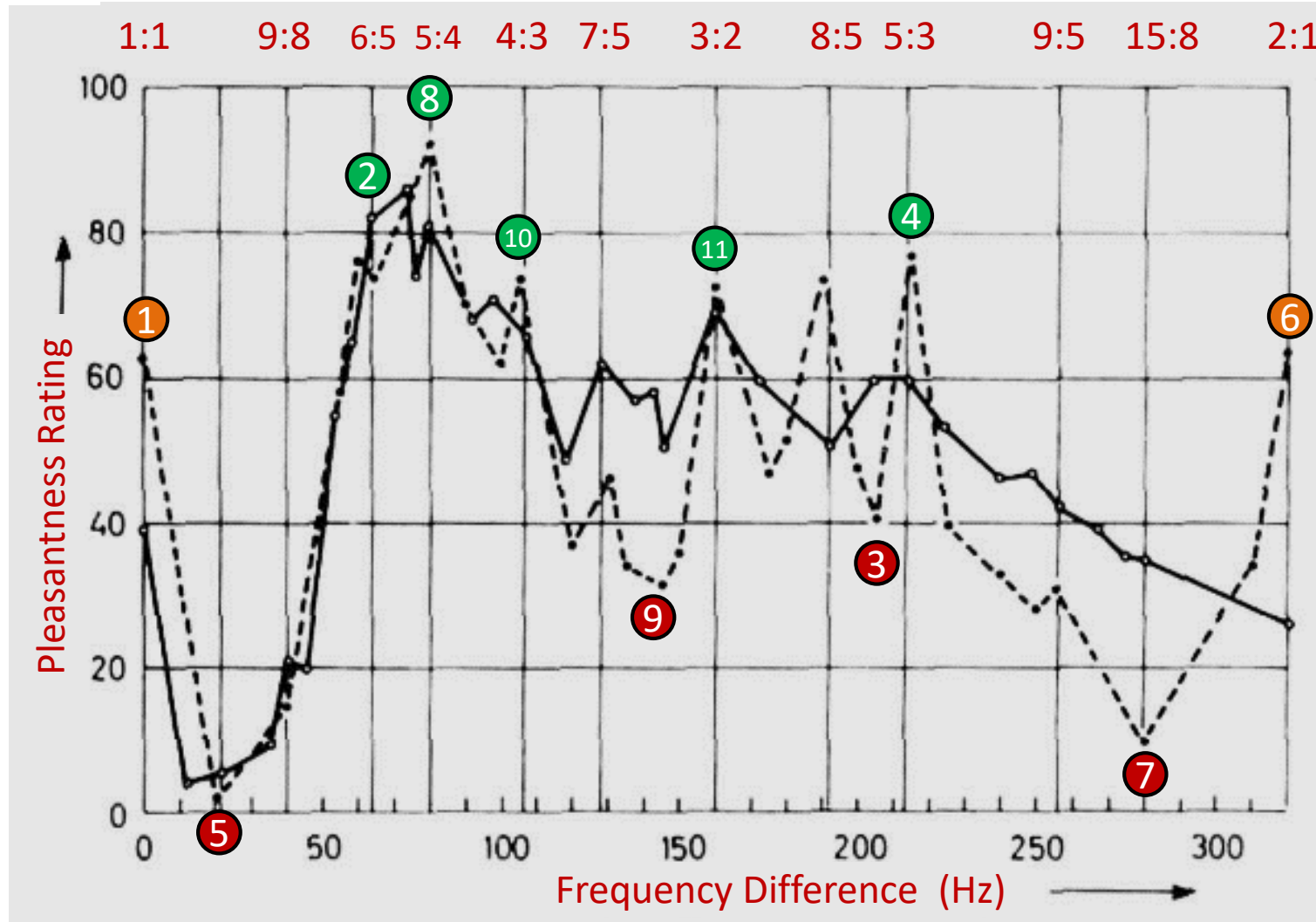
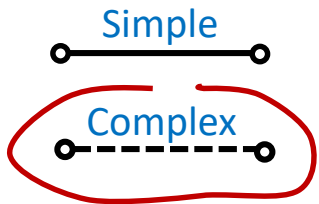
11 Tone Pairs to
Judge

Classic Measurement of Consonance

What you just heard...

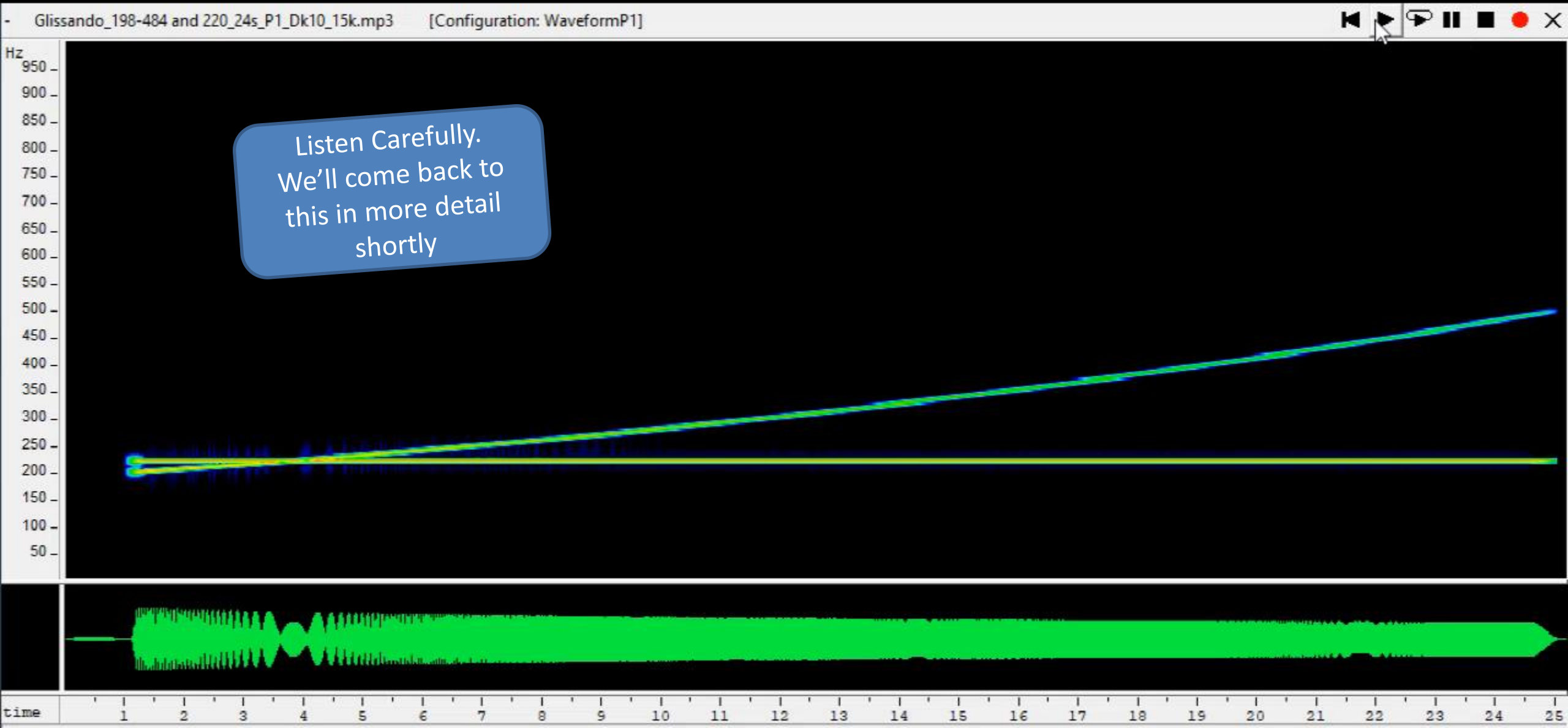
Drone:
320 Hz

Variable
Tone:
320-640 Hz



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

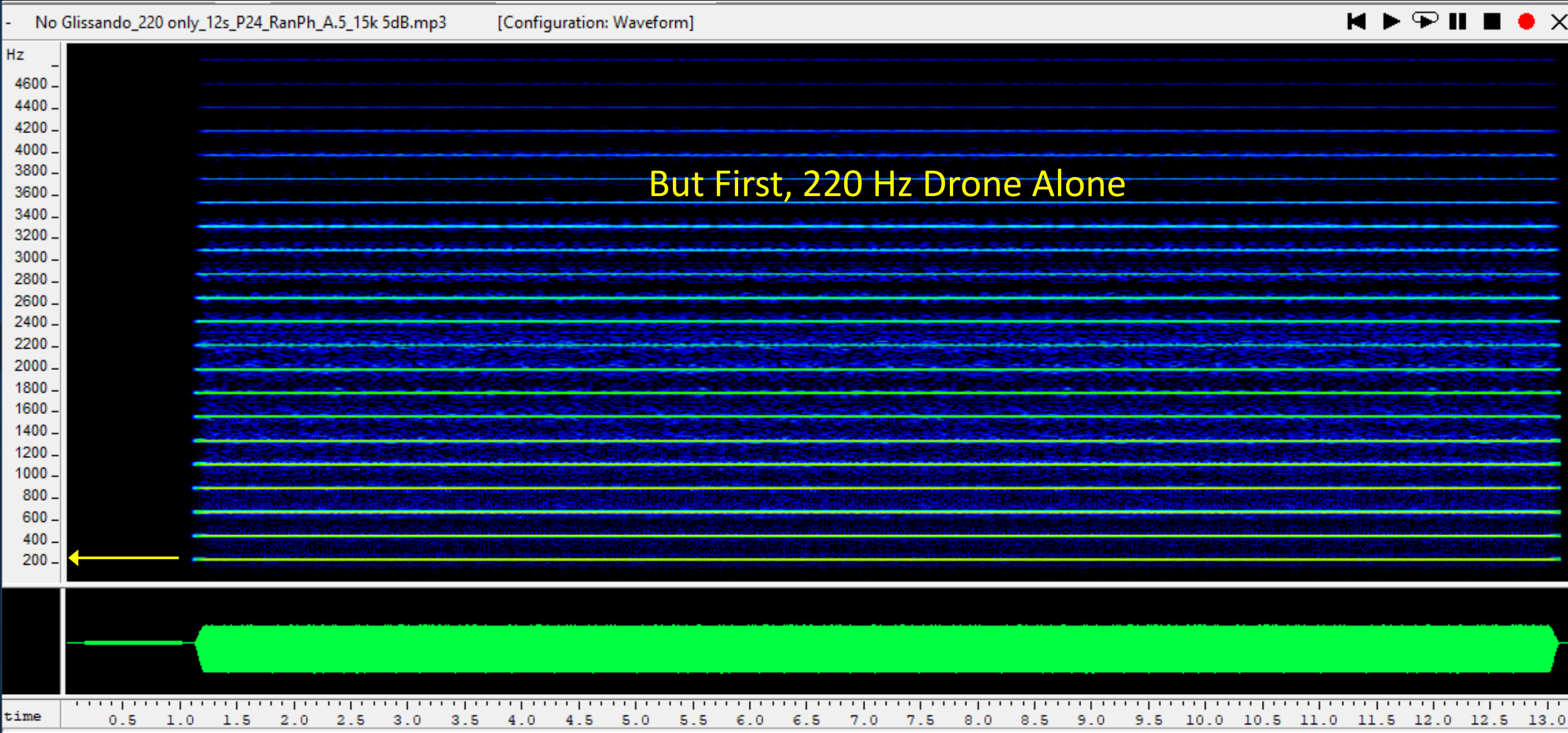
Consonance of *Simple* Tones: 220 Hz Drone vs. Variable Frequency over an Octave



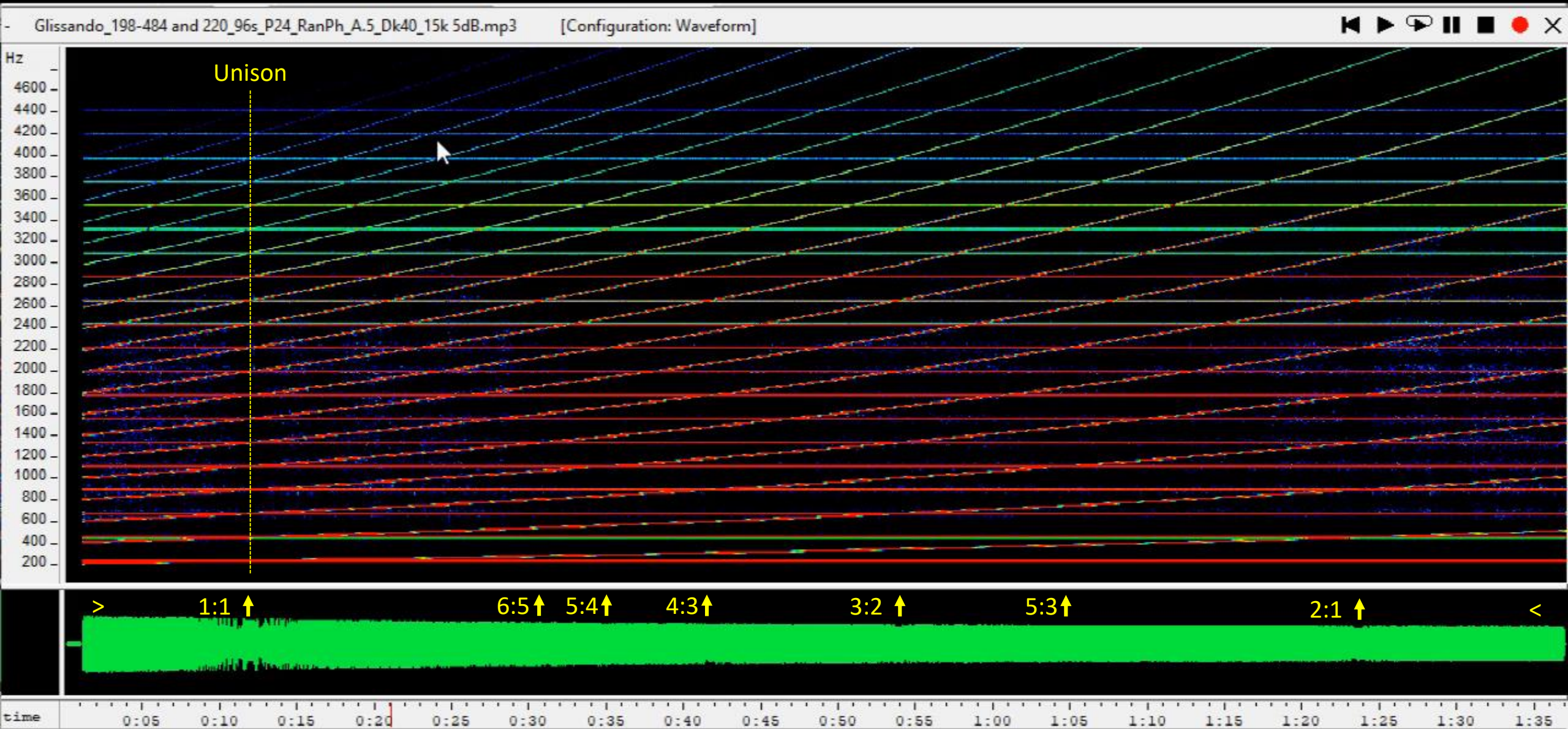
Listen Carefully.
We'll come back to
this in more detail
shortly



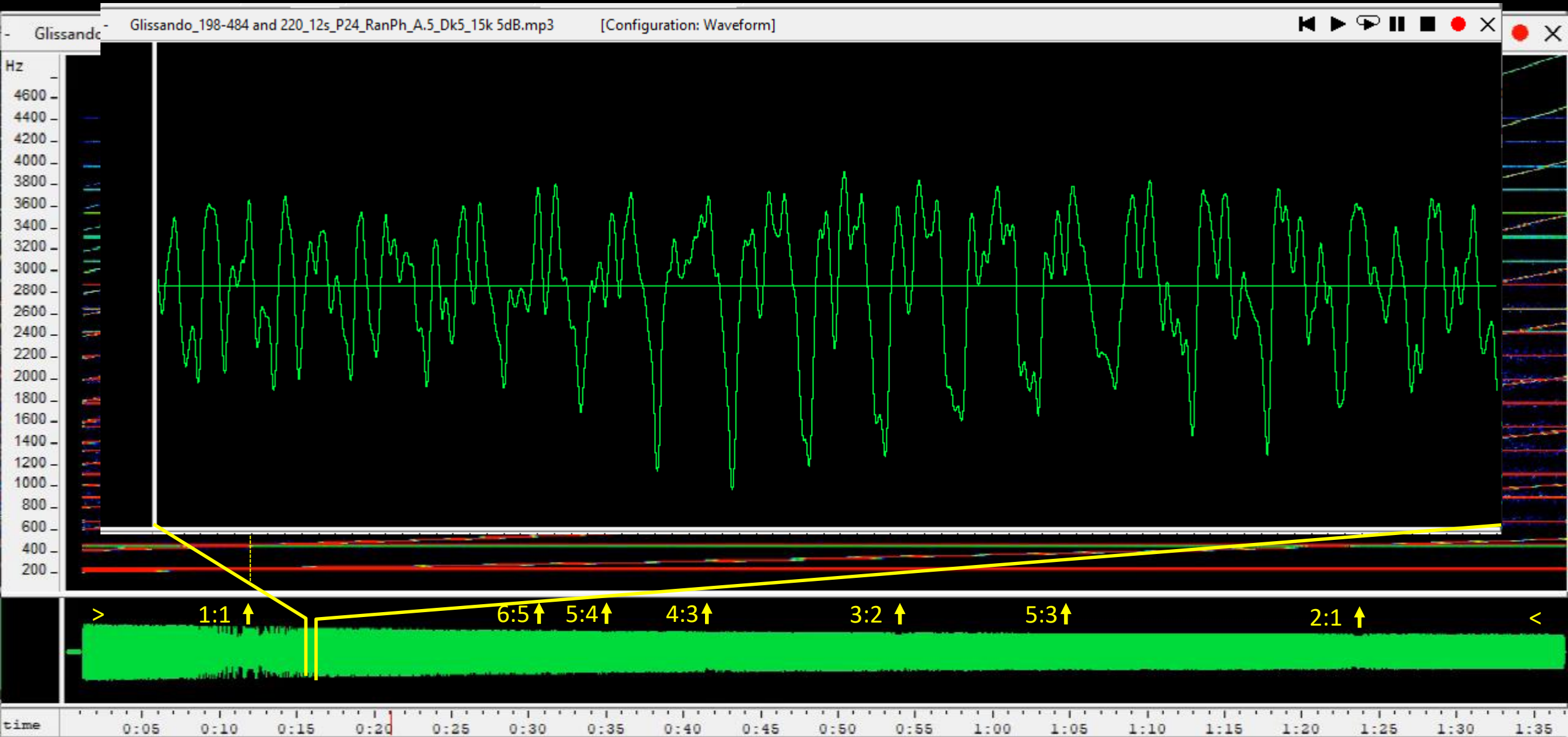
Mixing Two *Complex* Tones: 220 Hz Drone + Increasing Tone, 24 harmonics



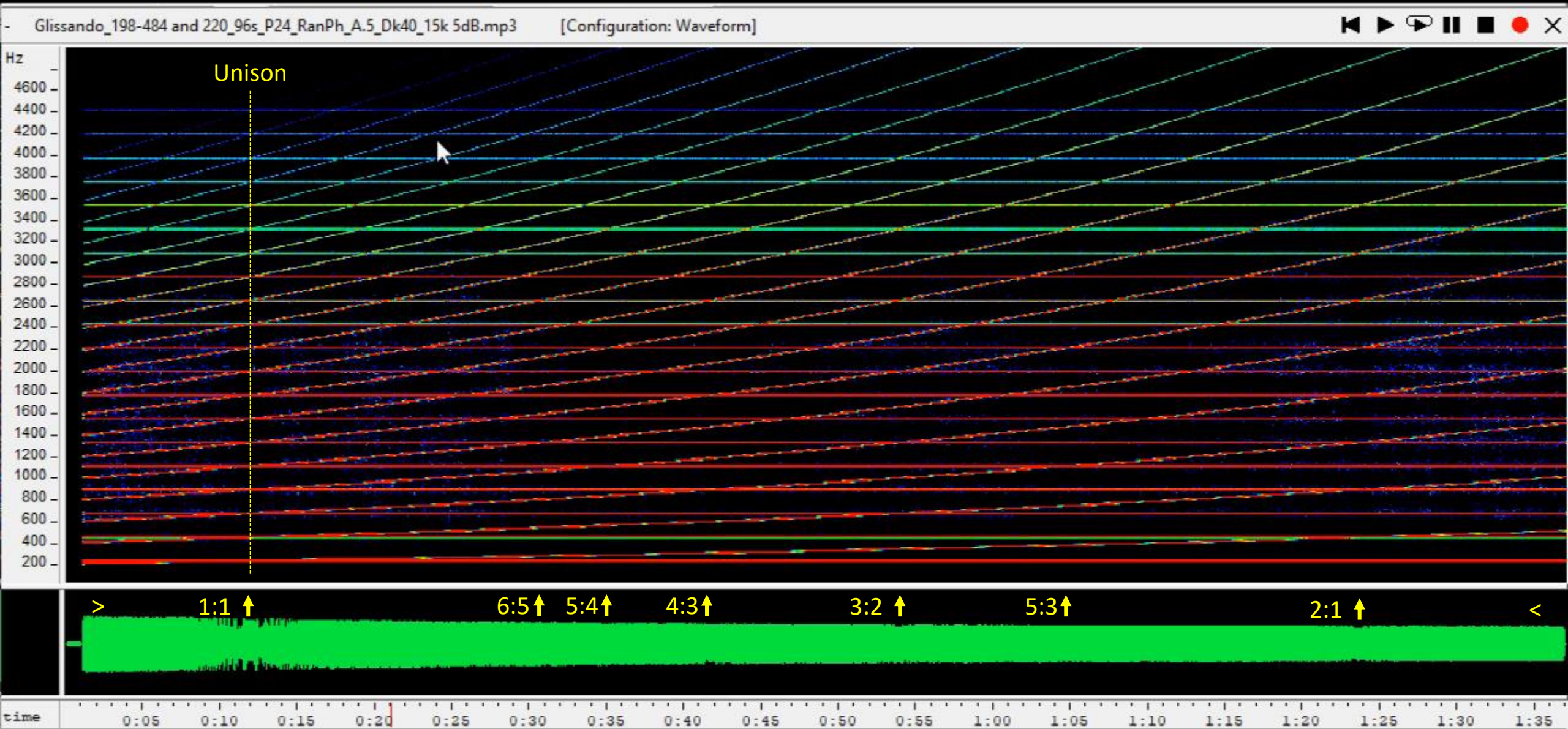
Mixing Two Complex Tones: 220 Hz Drone + Increasing Tone, 24 harmonics



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



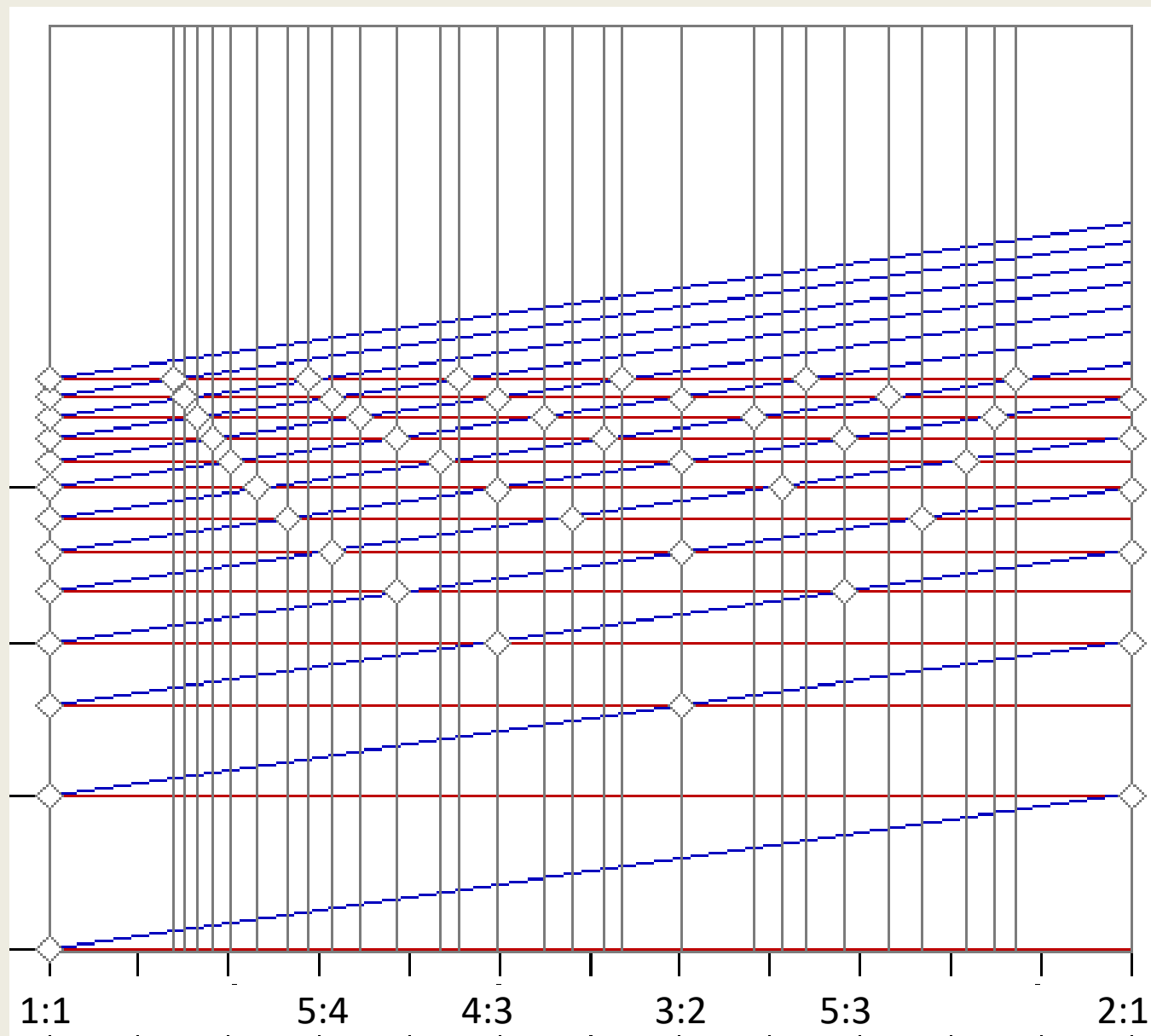
Two-tone Consonance Graph

12 Harmonics,
Log-Log Scales

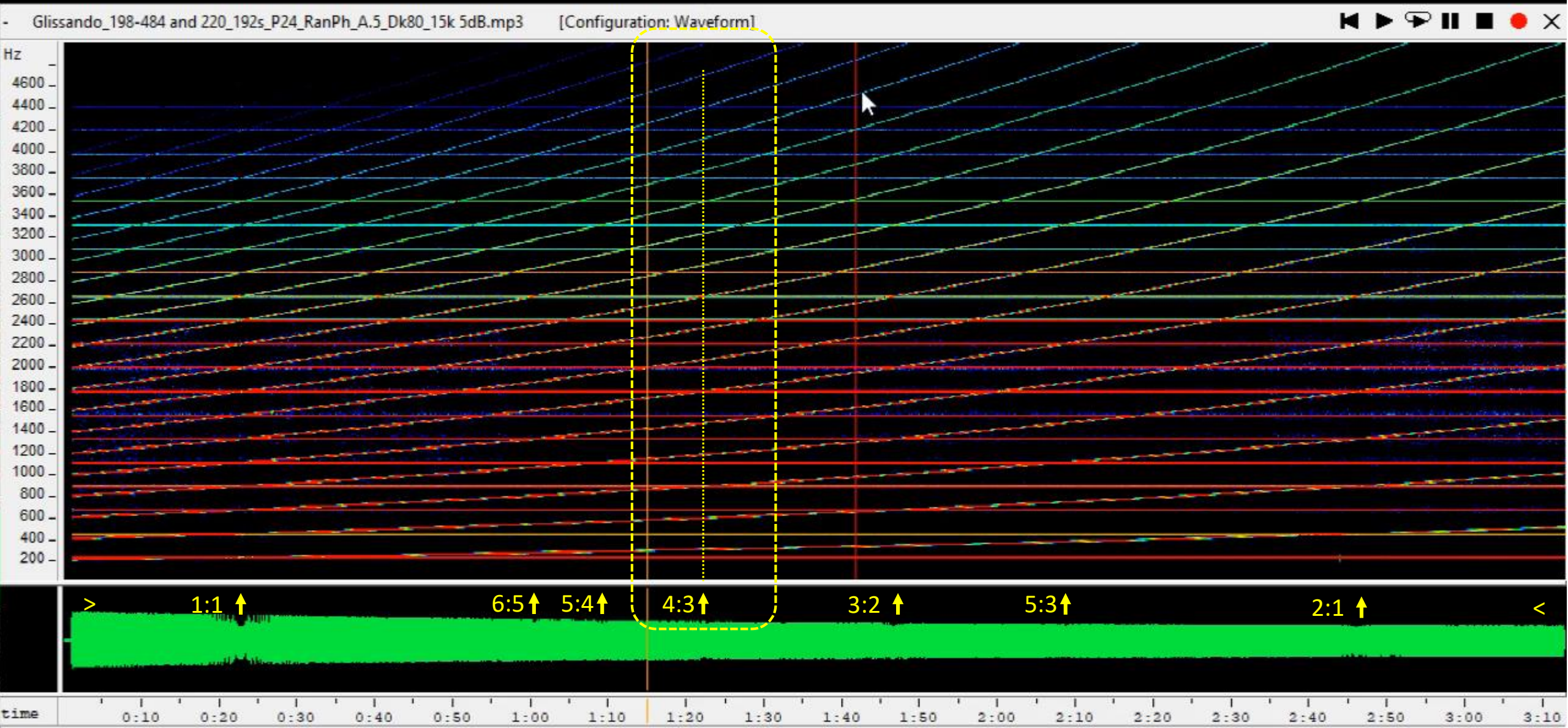
Red Tone Fixed

Blue Tone Increases
by 1 Octave
from Left to Right

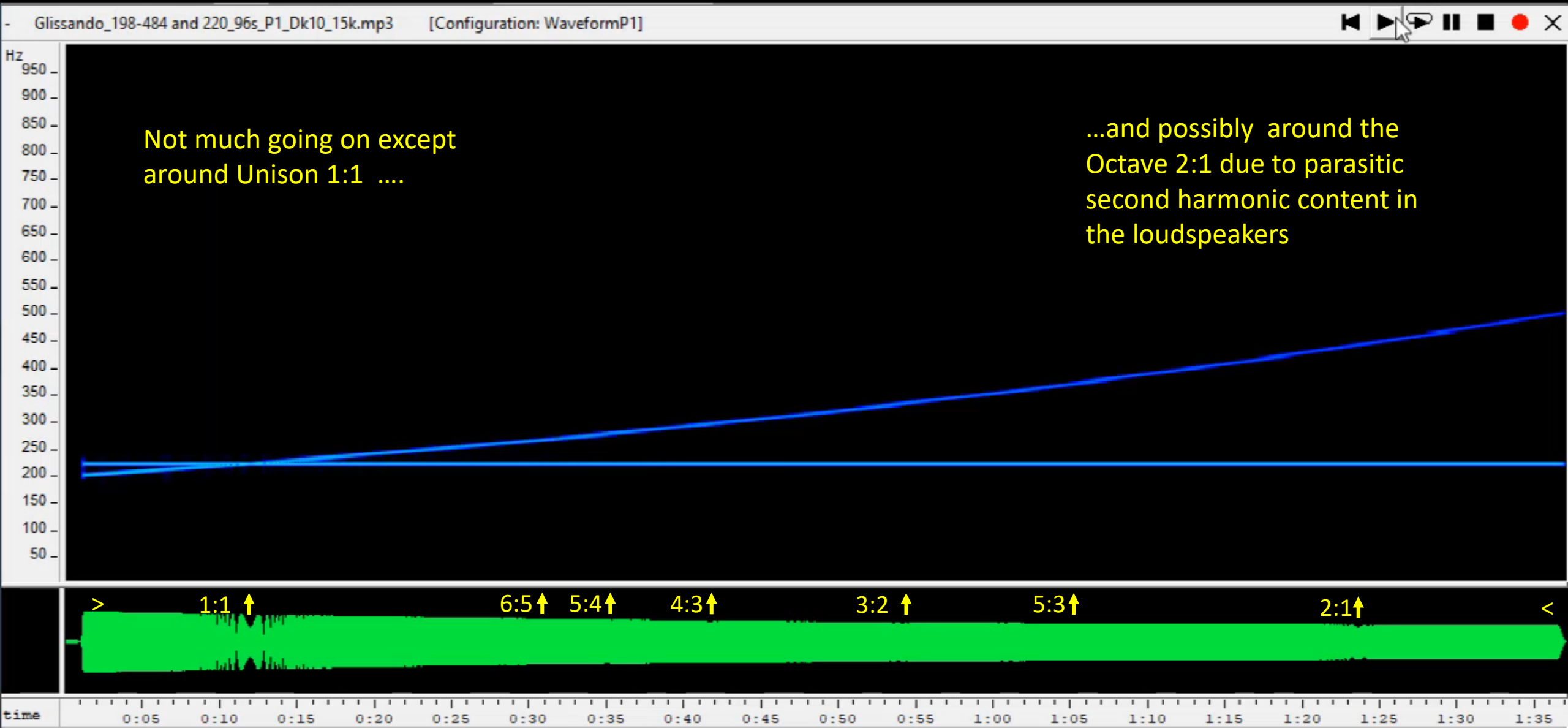
Diamonds \diamond show
coincidences of
Harmonics leading
to Consonances



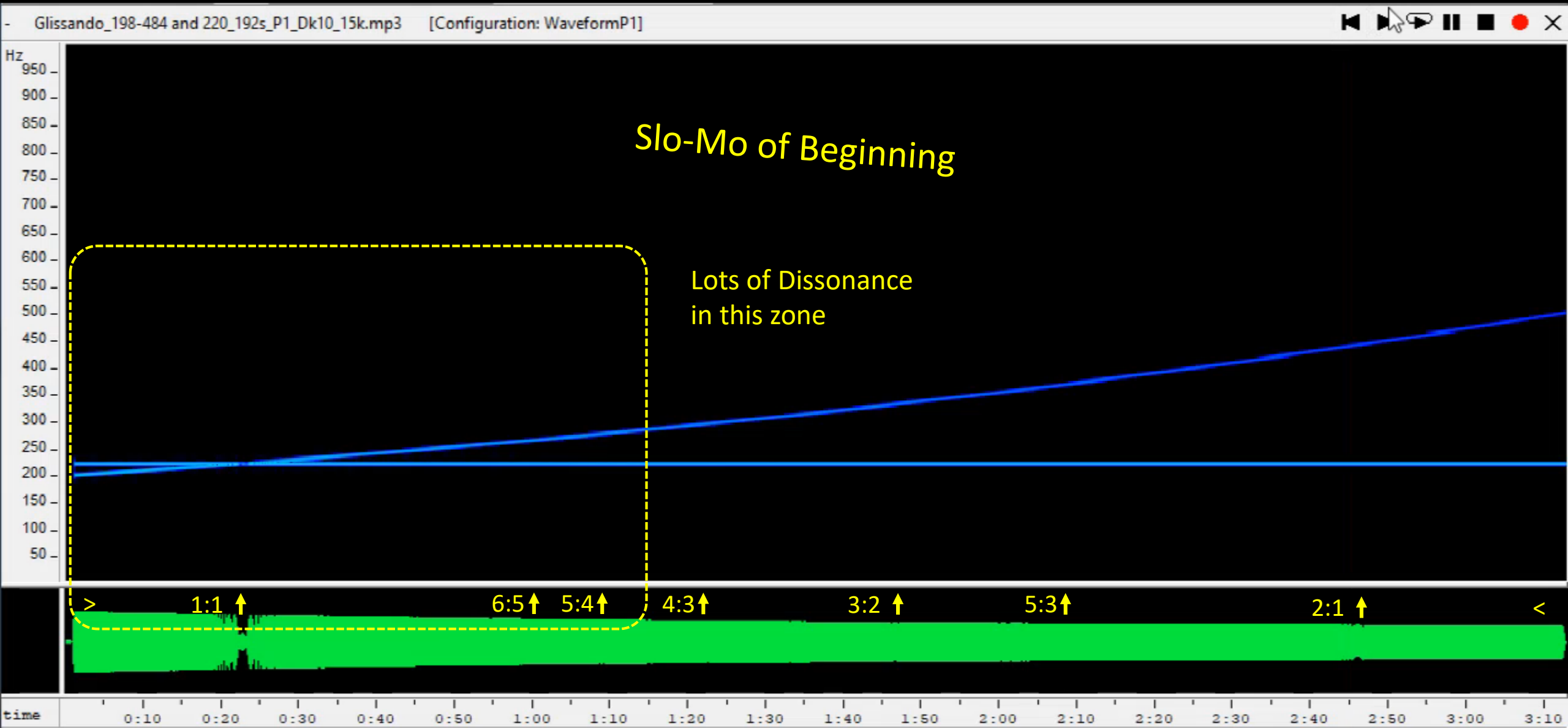
Mixing Two Complex Tones: Vicinity of 'Perfect Fourth' in Slo-Mo



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



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



2 Things to Remember Today

3:2 = A 'Fifth'



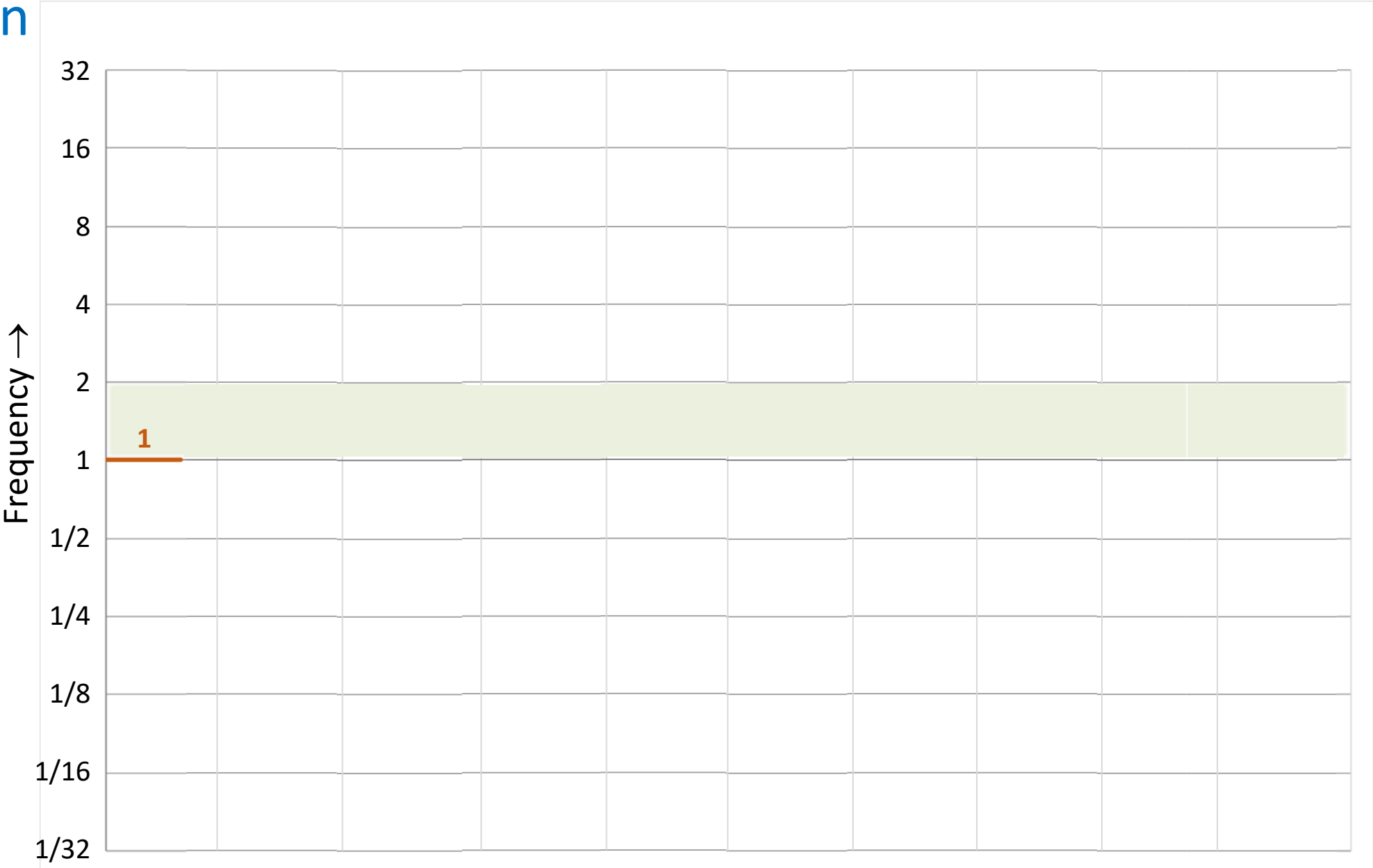
$\frac{531441}{524288}$ = The 'Pythagorean Comma'

Pythagorean

Scales: Stacking “Fifths”

Keep
multiplying
by $3/2$

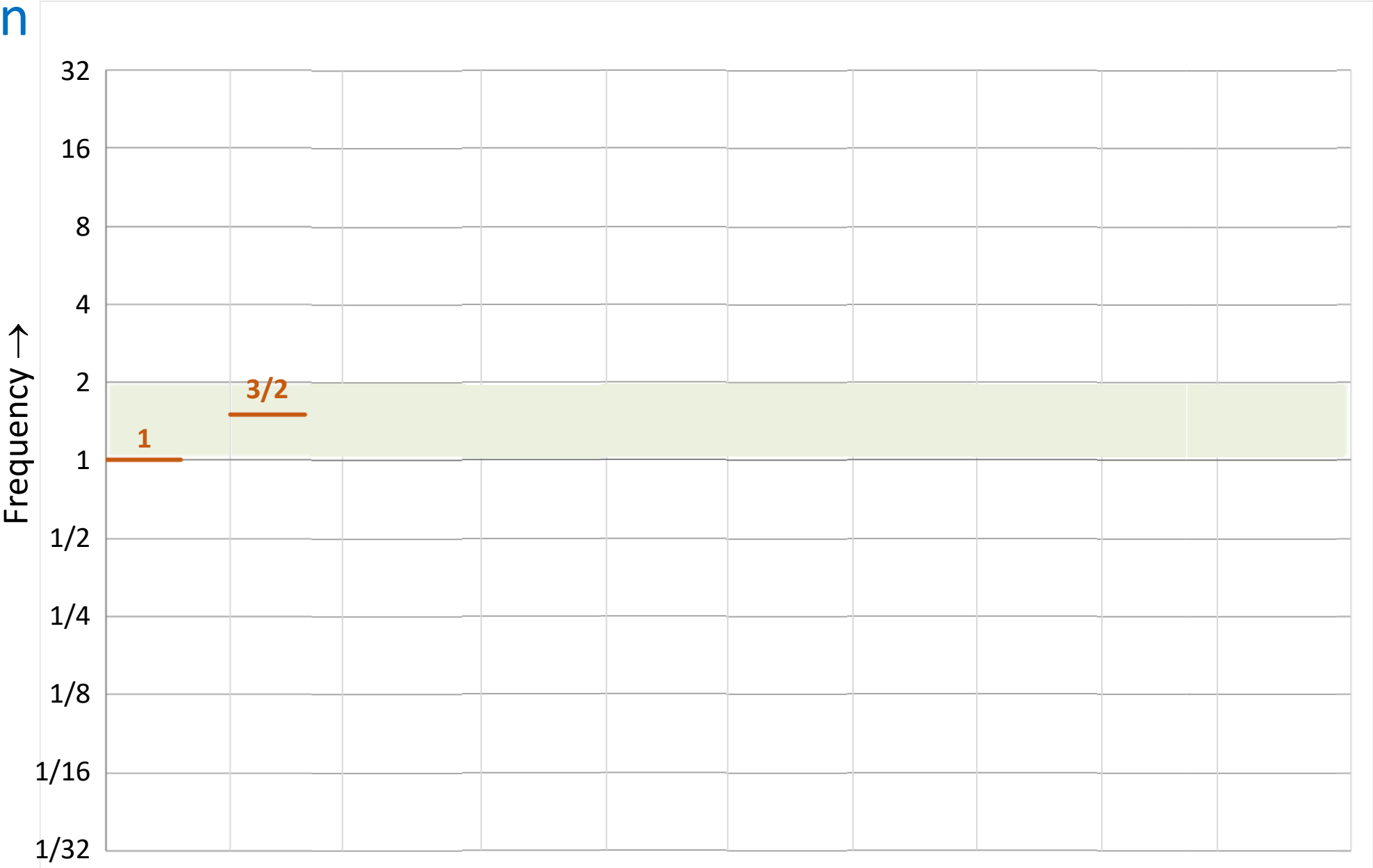
*...and folding
down to
base octave*



Pythagorean Scales: Stacking “Fifths”

Keep multiplying by $3/2$

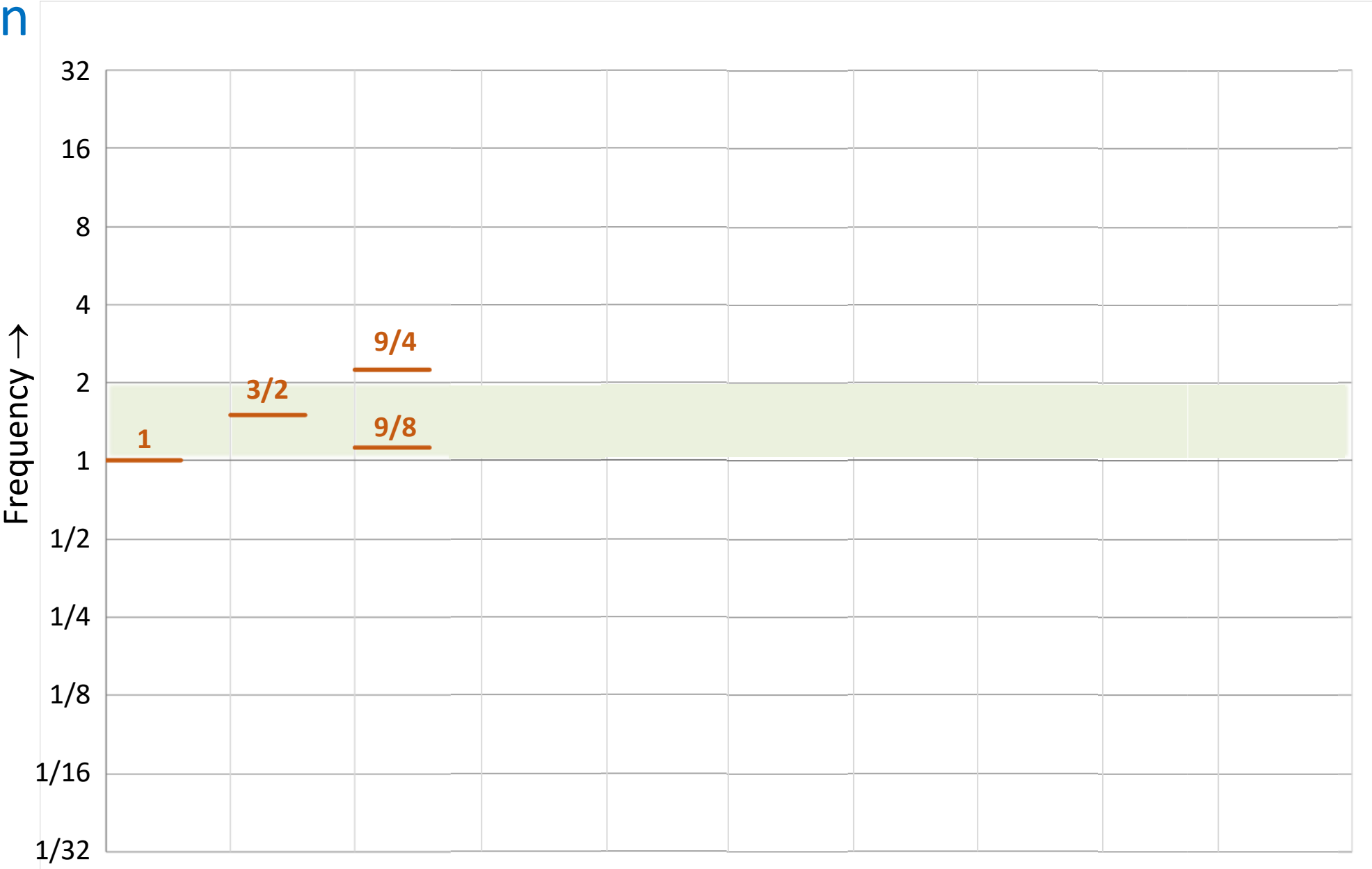
...and folding down to base octave



Pythagorean Scales: Stacking “Fifths”

Keep multiplying by $3/2$

...and folding down to base octave

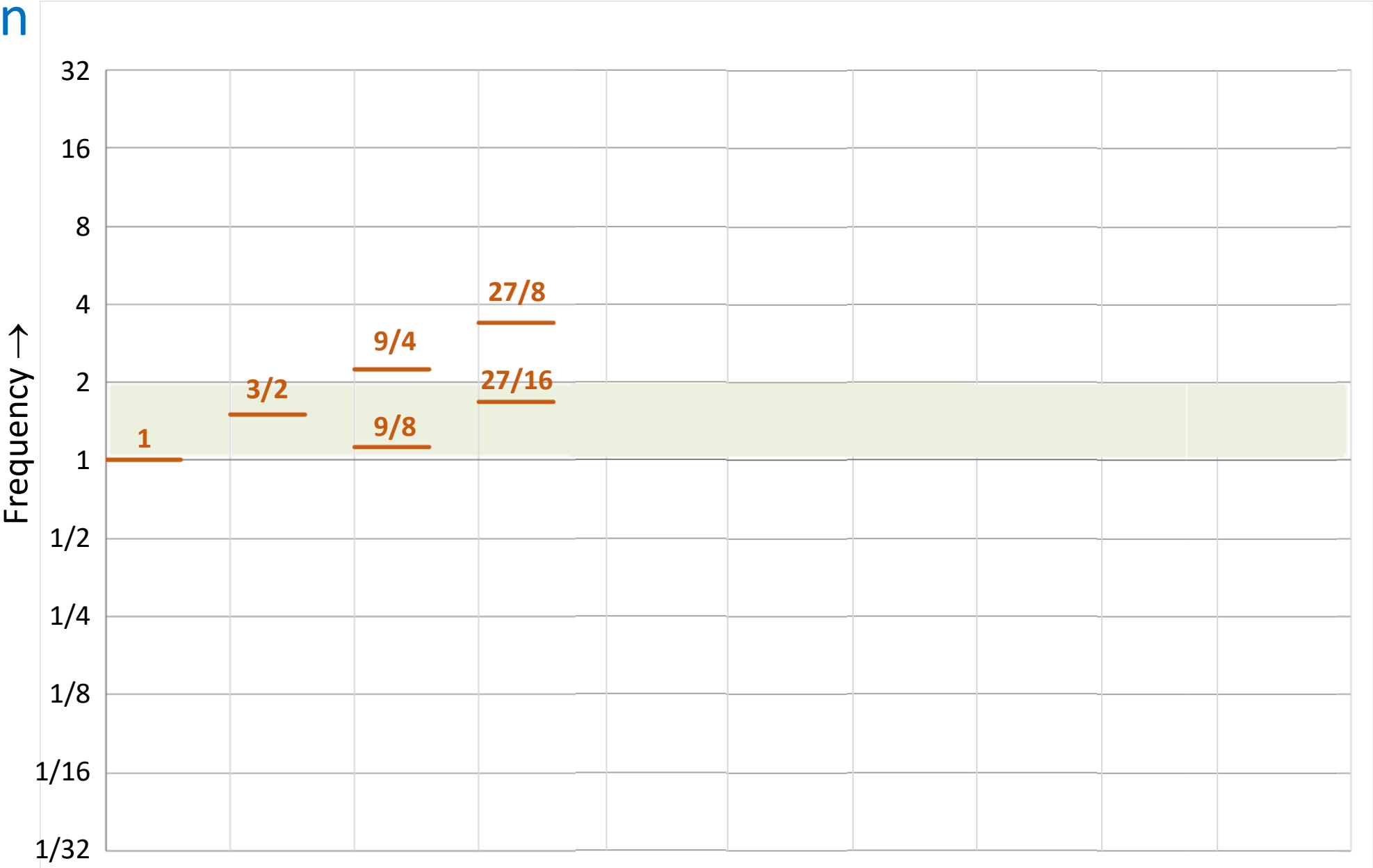


Pythagorean

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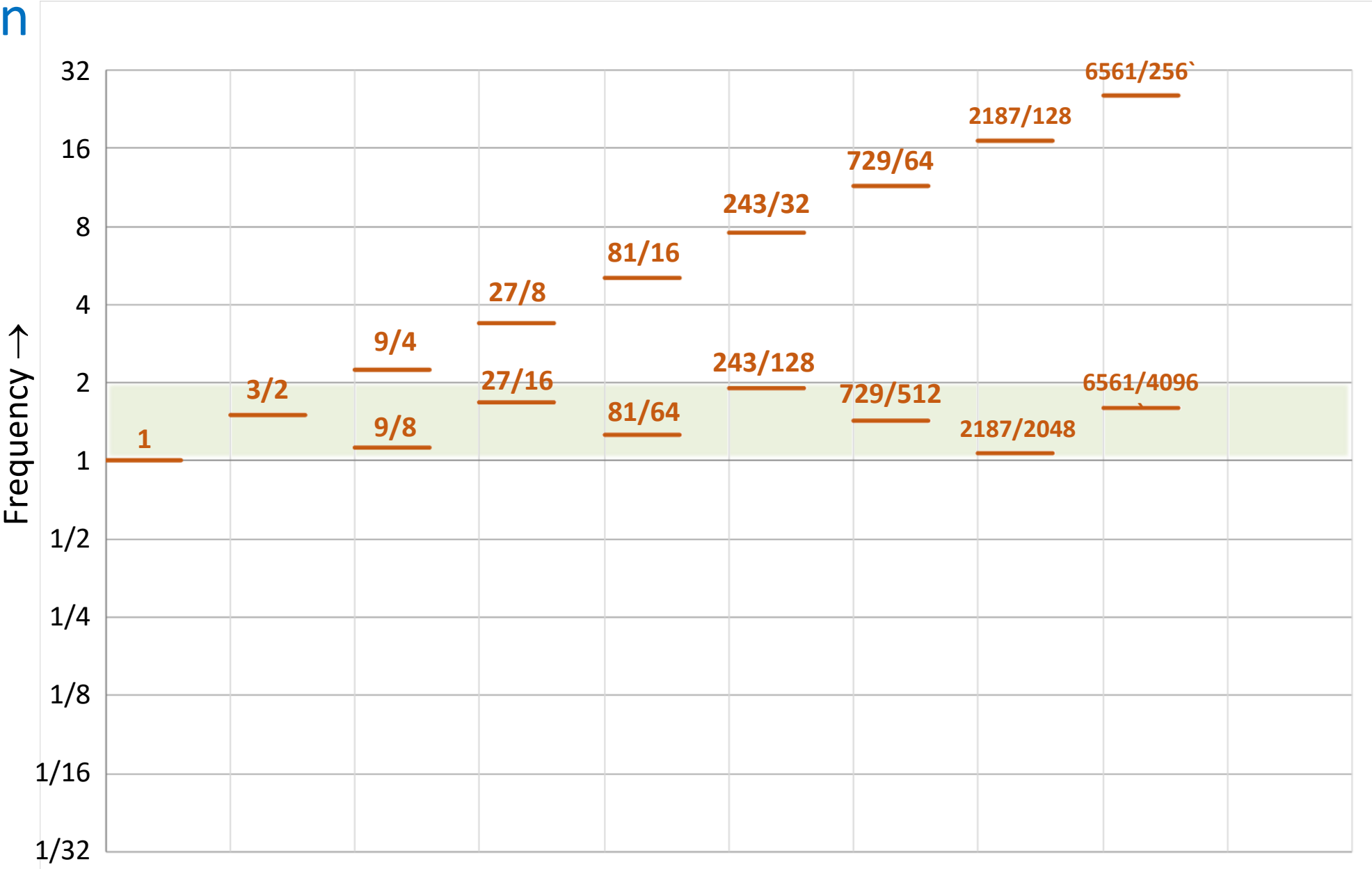


Pythagorean

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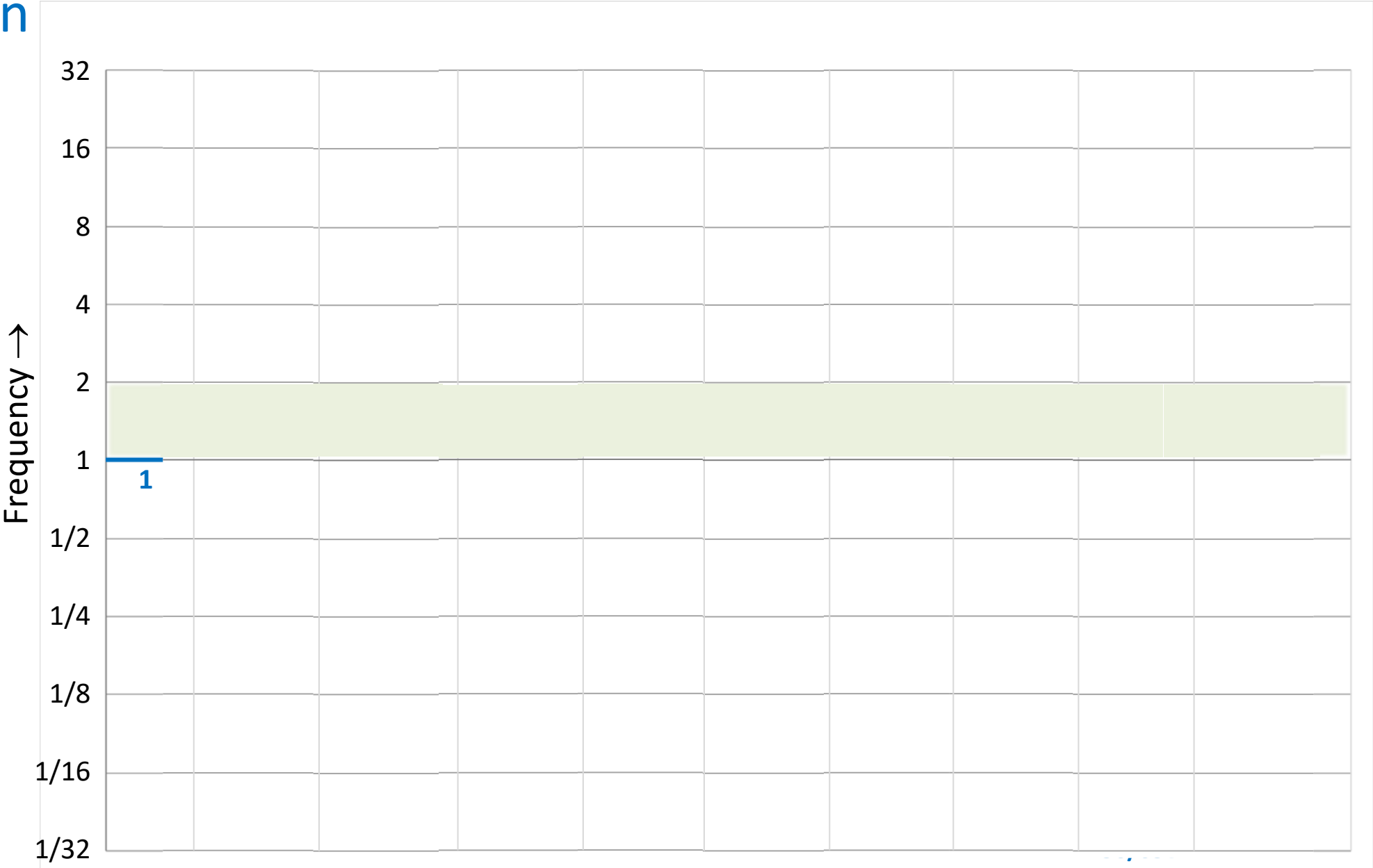
*...and folding
down to
base octave*



Pythagorean

Scales: Stacking “Fifths”

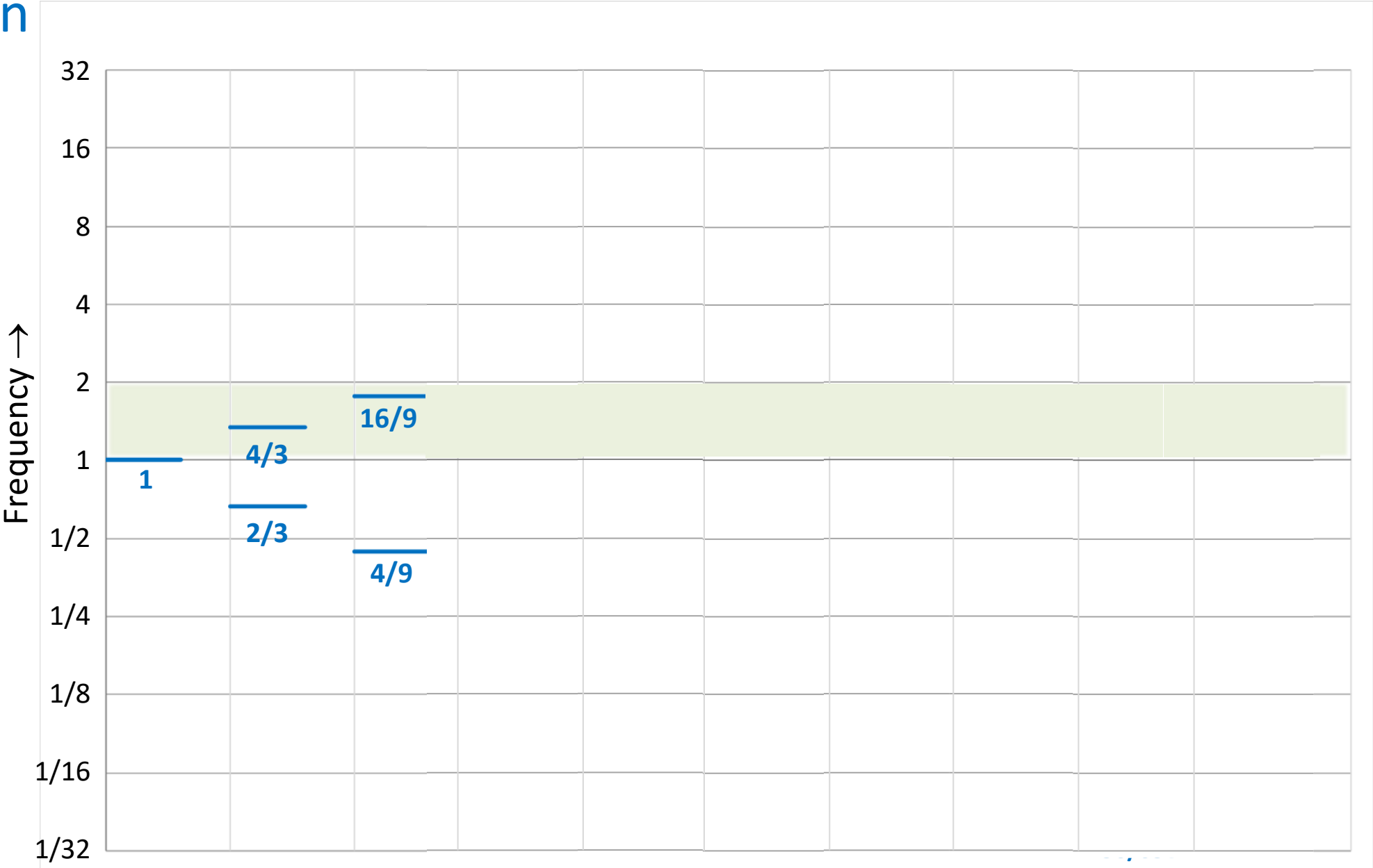
also go down
by fifths –
dividing
repeatedly
by $3/2$



Pythagorean

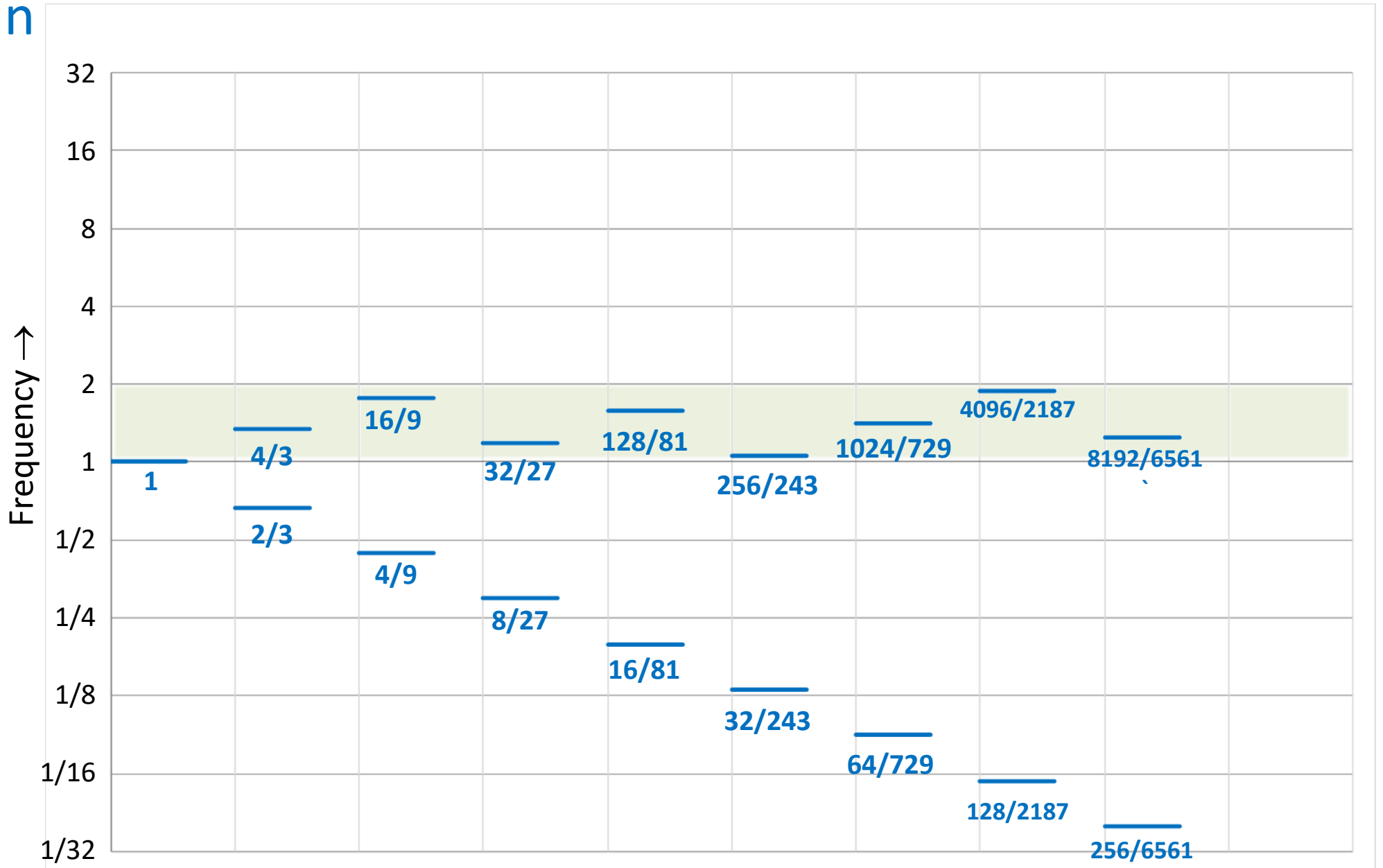
Scales: Stacking “Fifths”

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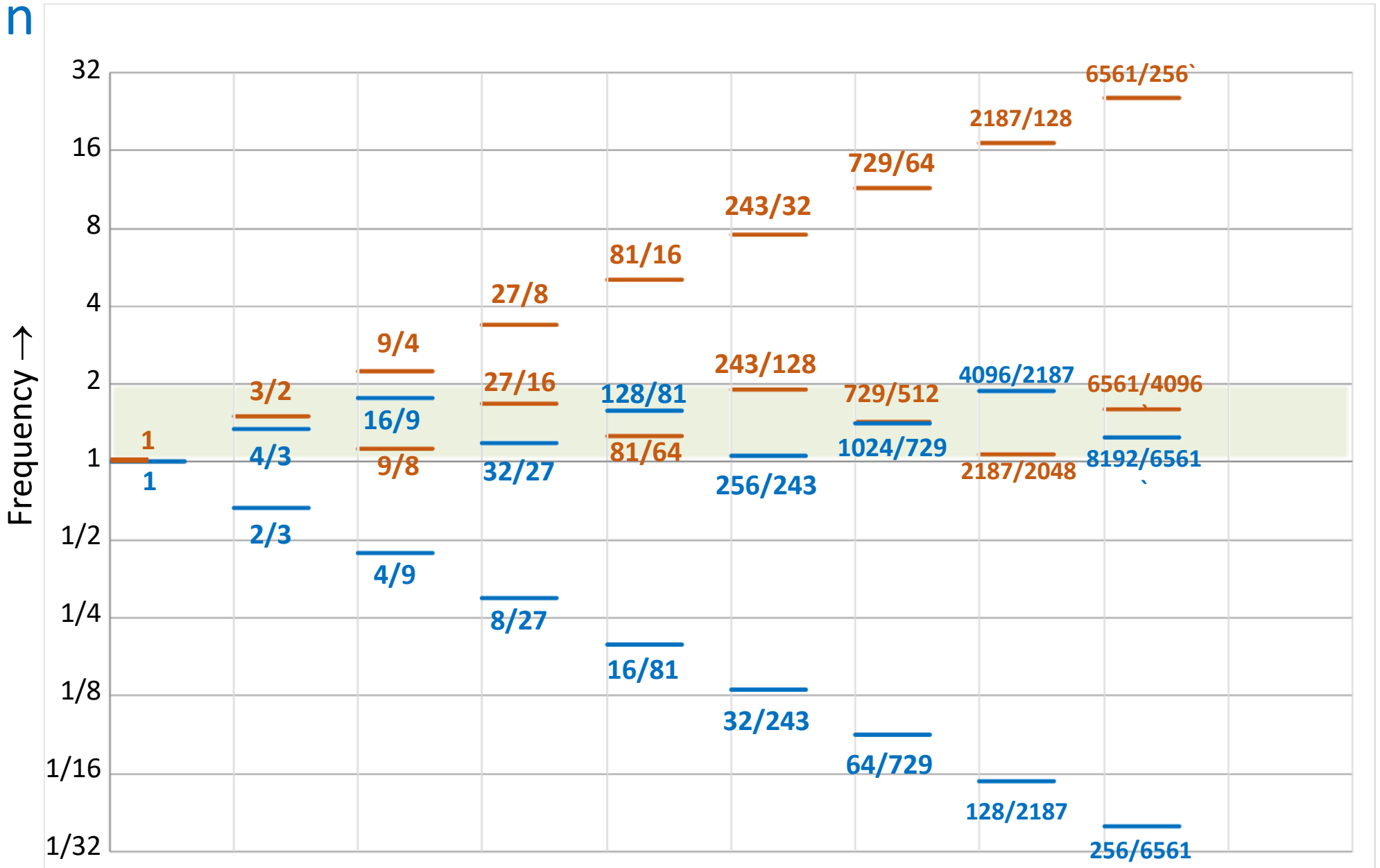


Pythagorean Scales: Stacking “Fifths”

also go down
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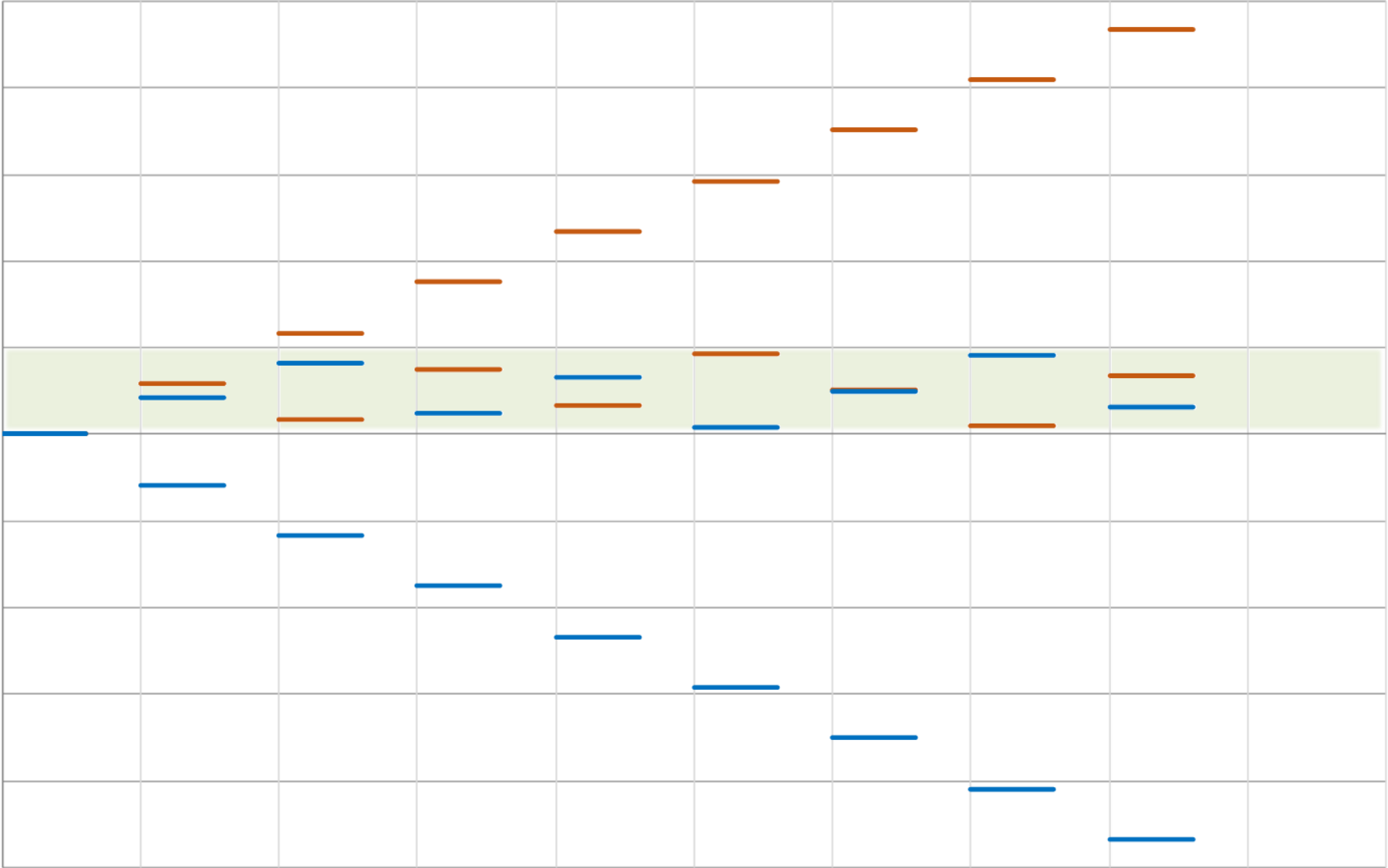
Pythagorean Scales: Stacking “Fifths”



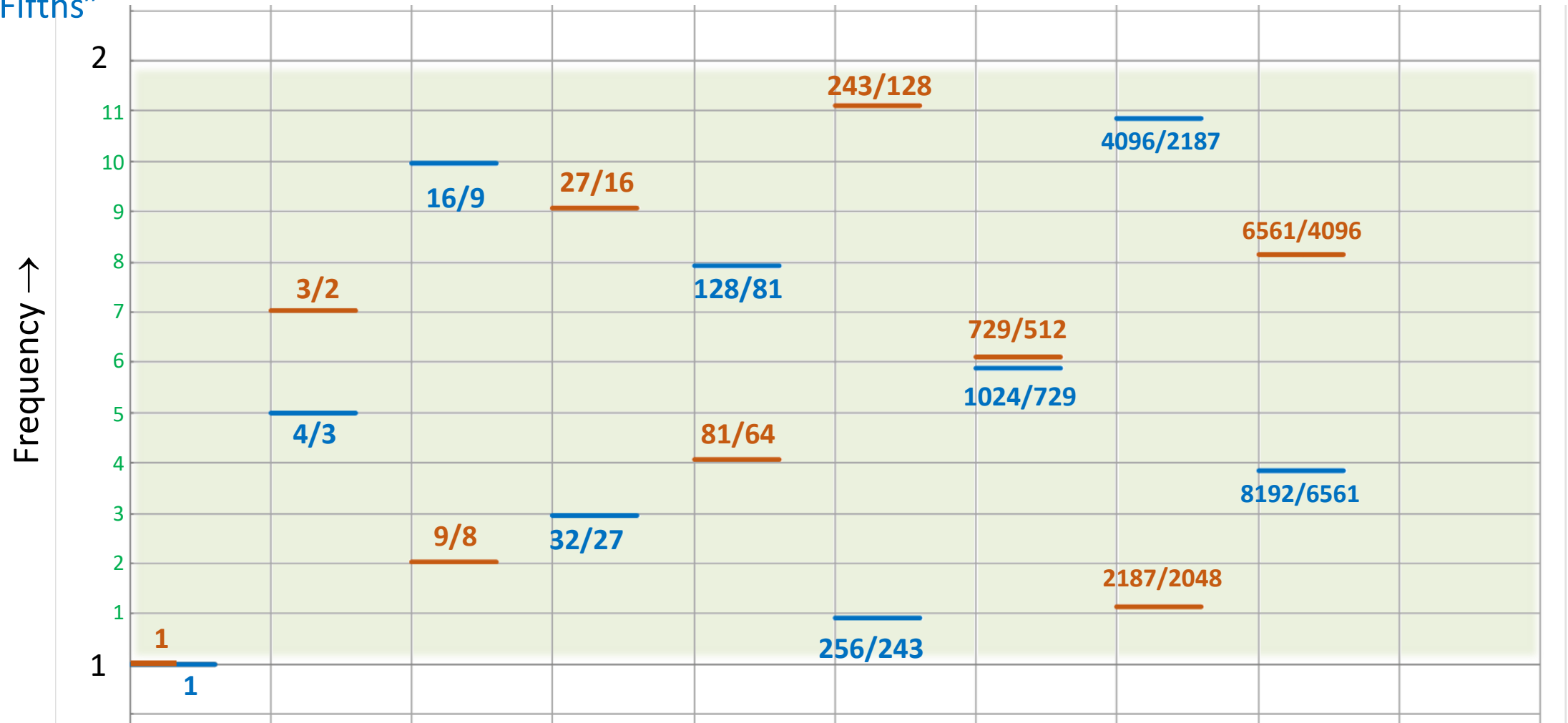
Pythagorean

Scales: Stacking “Fifths”

Now
collapse....



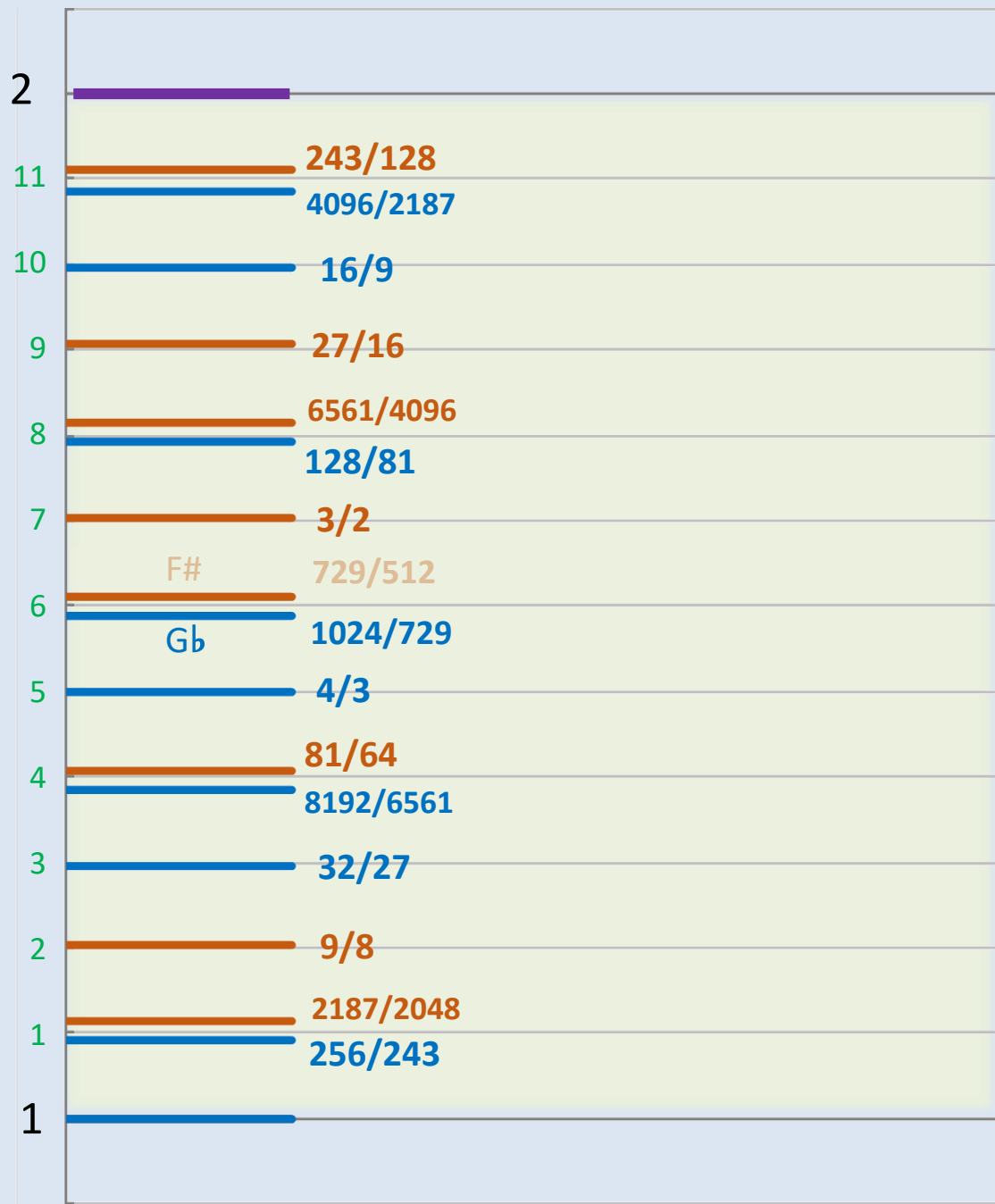
Pythagorean Scales: Stacking "Fifths"



The Pythagorean Scale

[used until ~1600 CE]

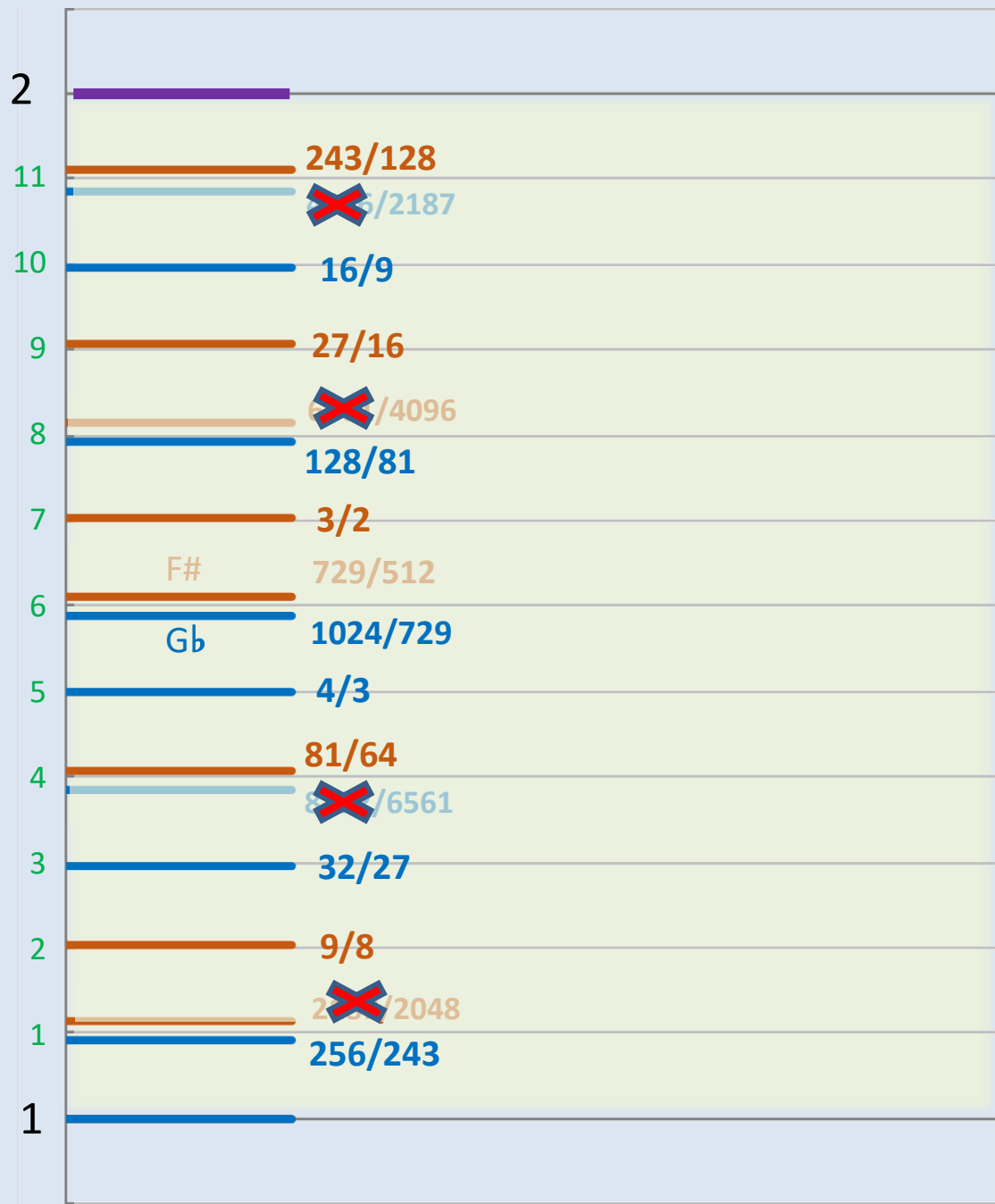
Frequency (log) ↑



The Pythagorean Scale

[used until ~1600 CE]

Frequency (log) ↑



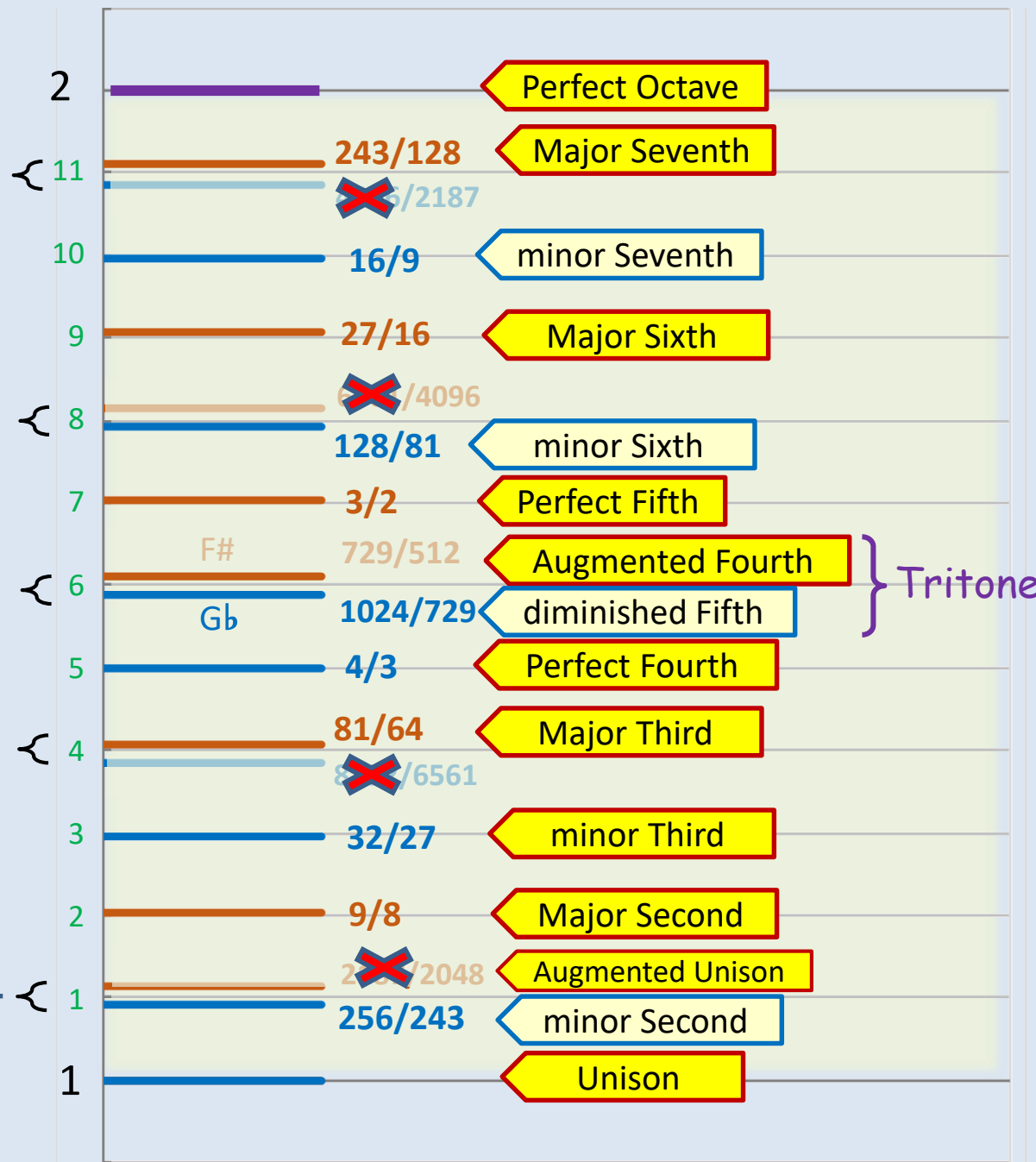
Sound of Music 8B



The Pythagorean Scale

[used until ~1600 CE]

Frequency (log) ↑



The Pythagorean Comma (Euclid)

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

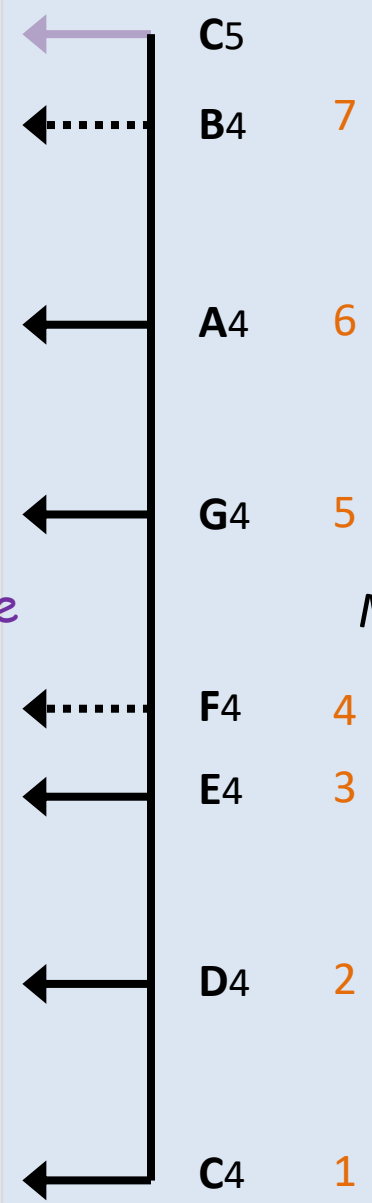
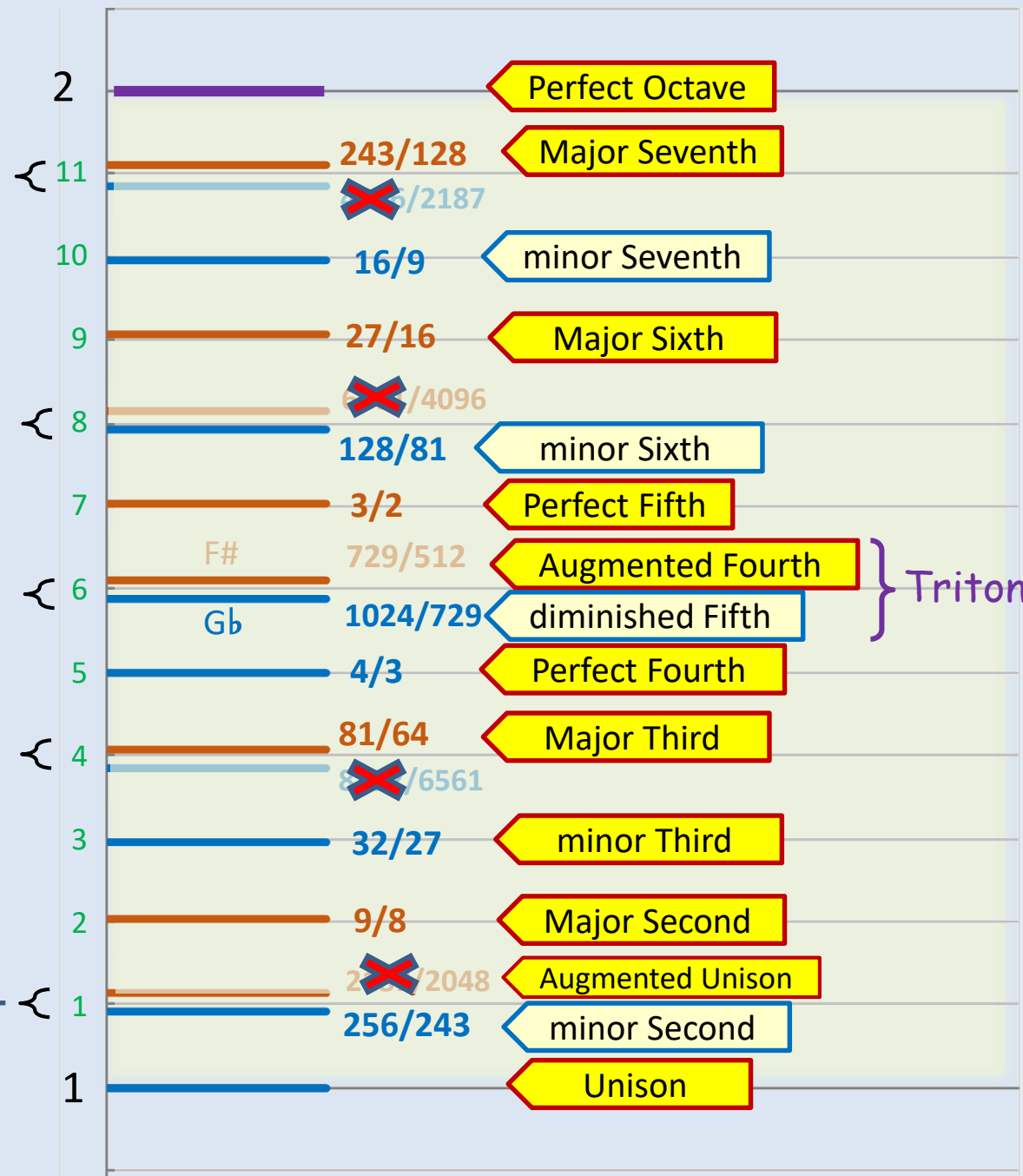
≈ 23.46 cents



The Pythagorean Scale

[used until ~1600 CE]

Frequency (log) ↑



Diatonic Major Scale

The Pythagorean Comma (Euclid)

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

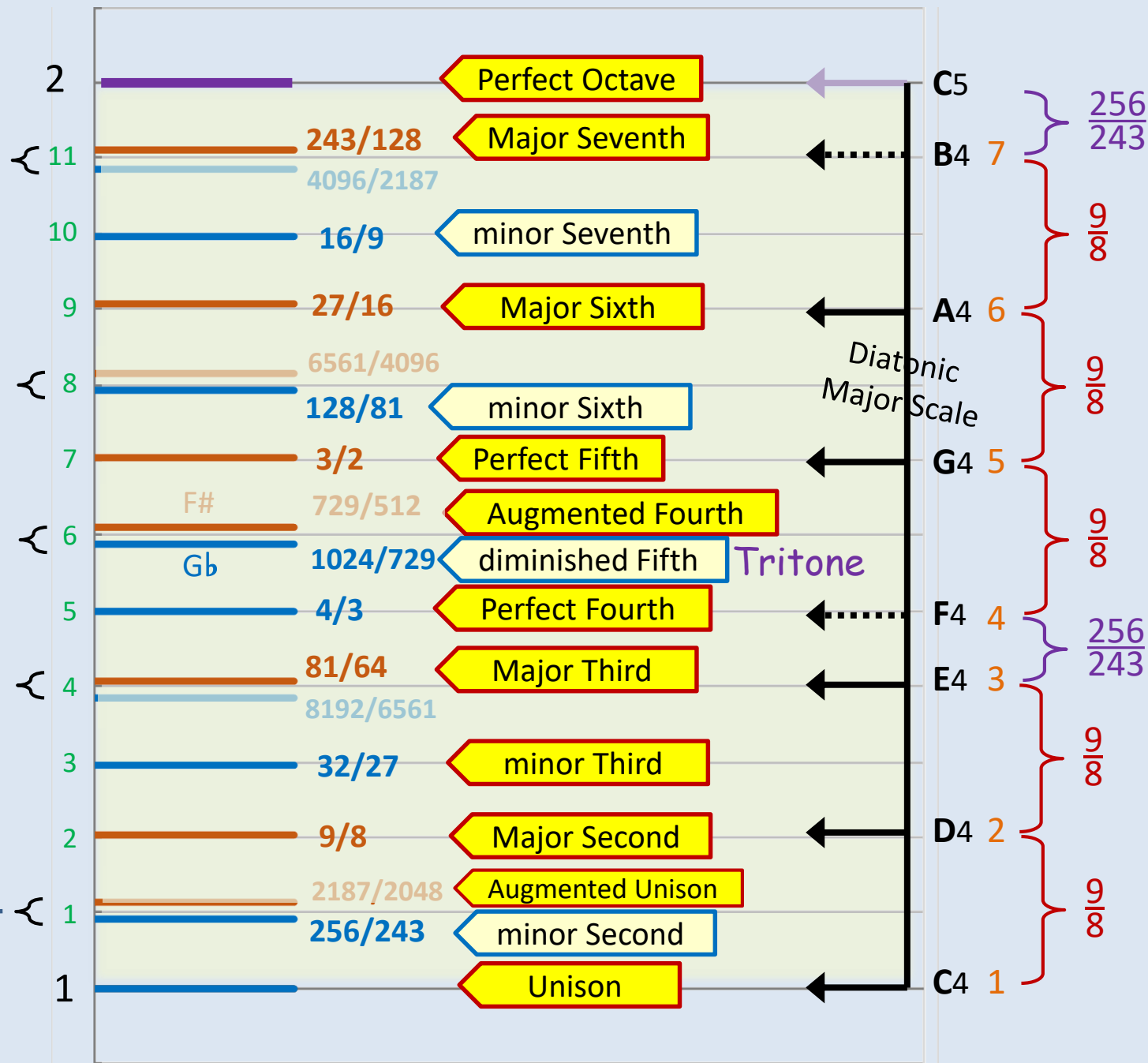
≈ 23.46 cents



The Pythagorean Scale

[used until ~1600 CE]

Frequency (log) ↑



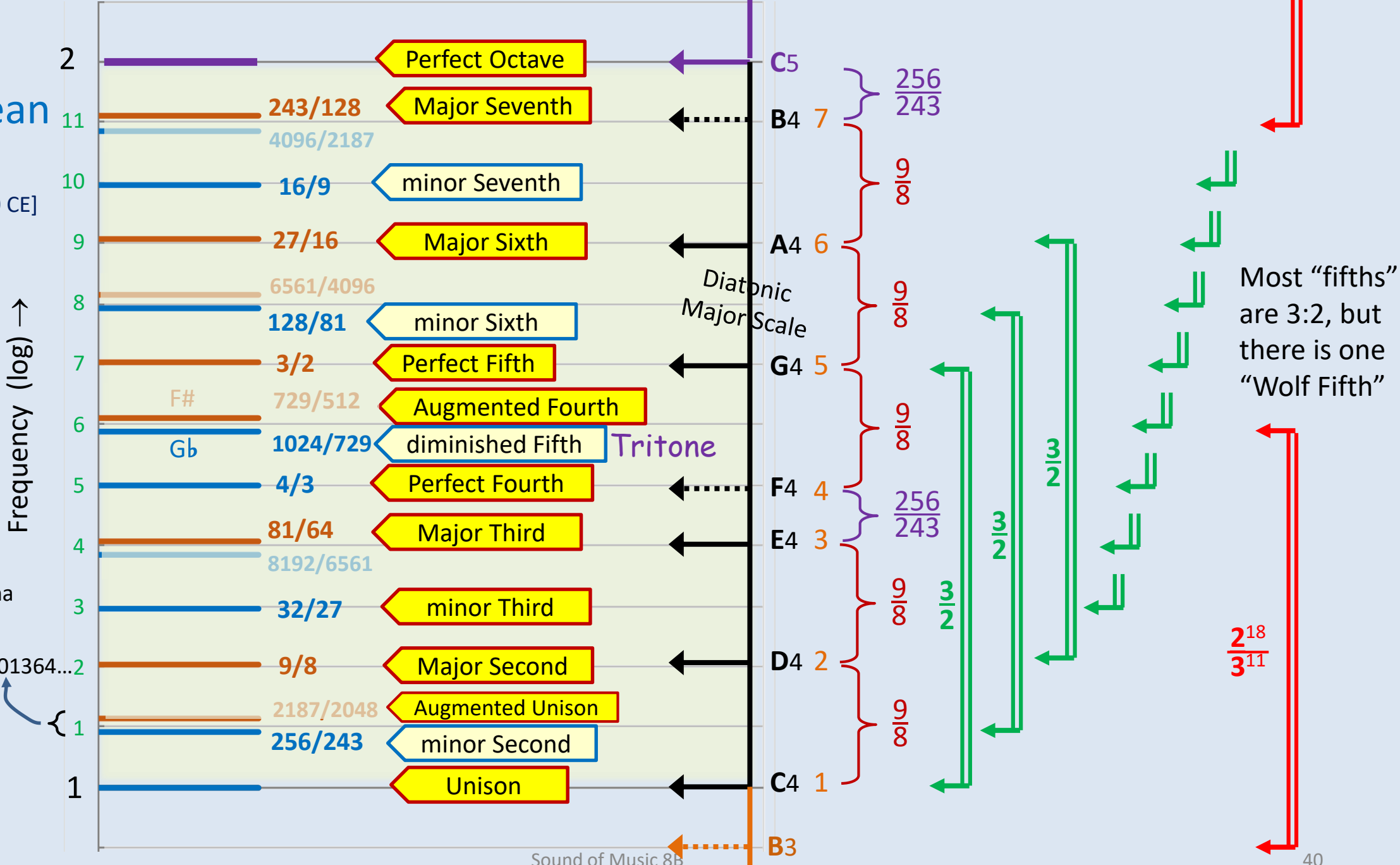
The Pythagorean Comma (Euclid)

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The Pythagorean Scale

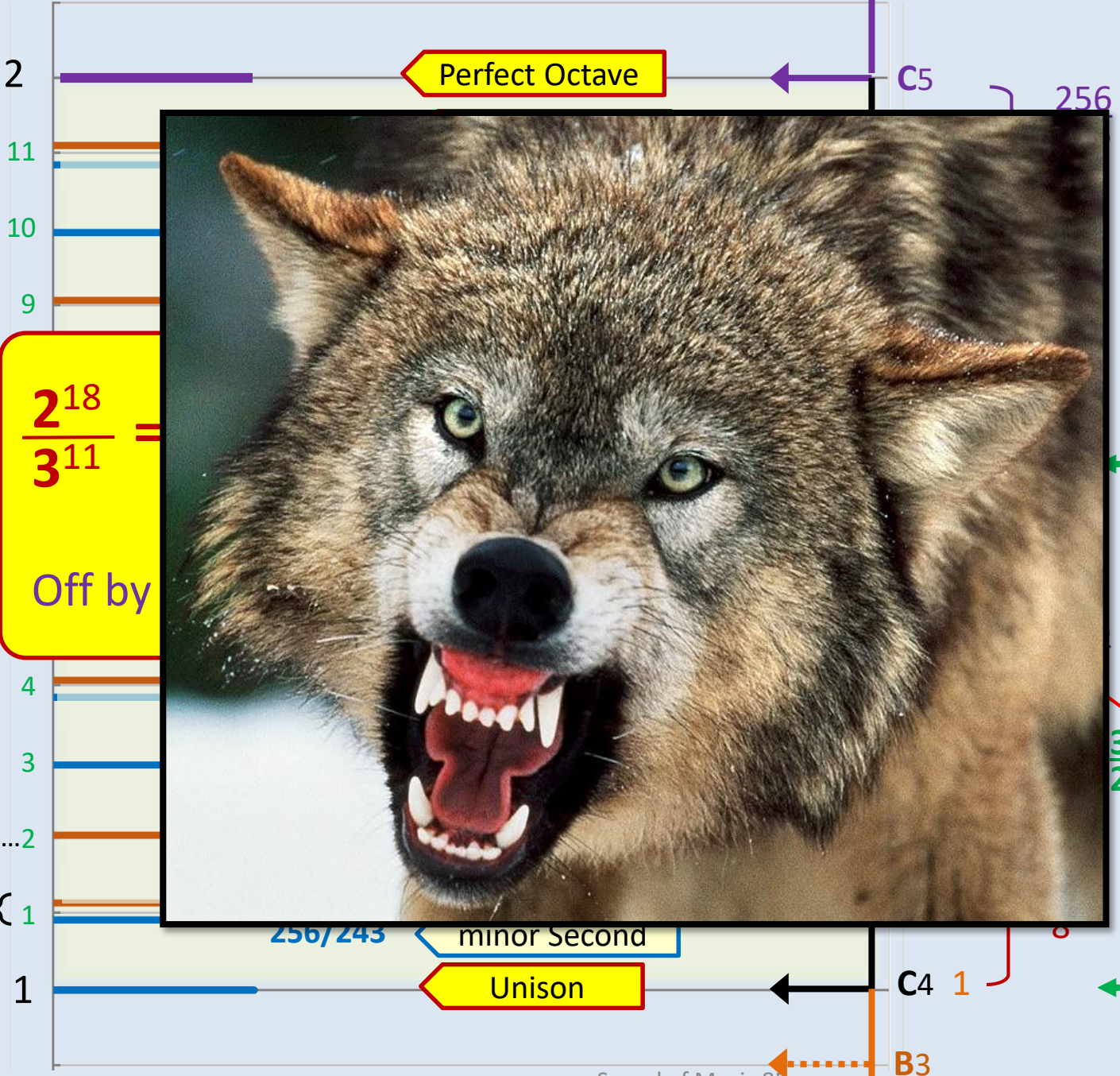
[used until ~1600 CE]



The Pythagorean Scale

[used until ~1600 CE]

Frequency (log) →



Pythagorean Comma (Euclid)

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

The Pythagorean Scale

[used until ~1600 CE]

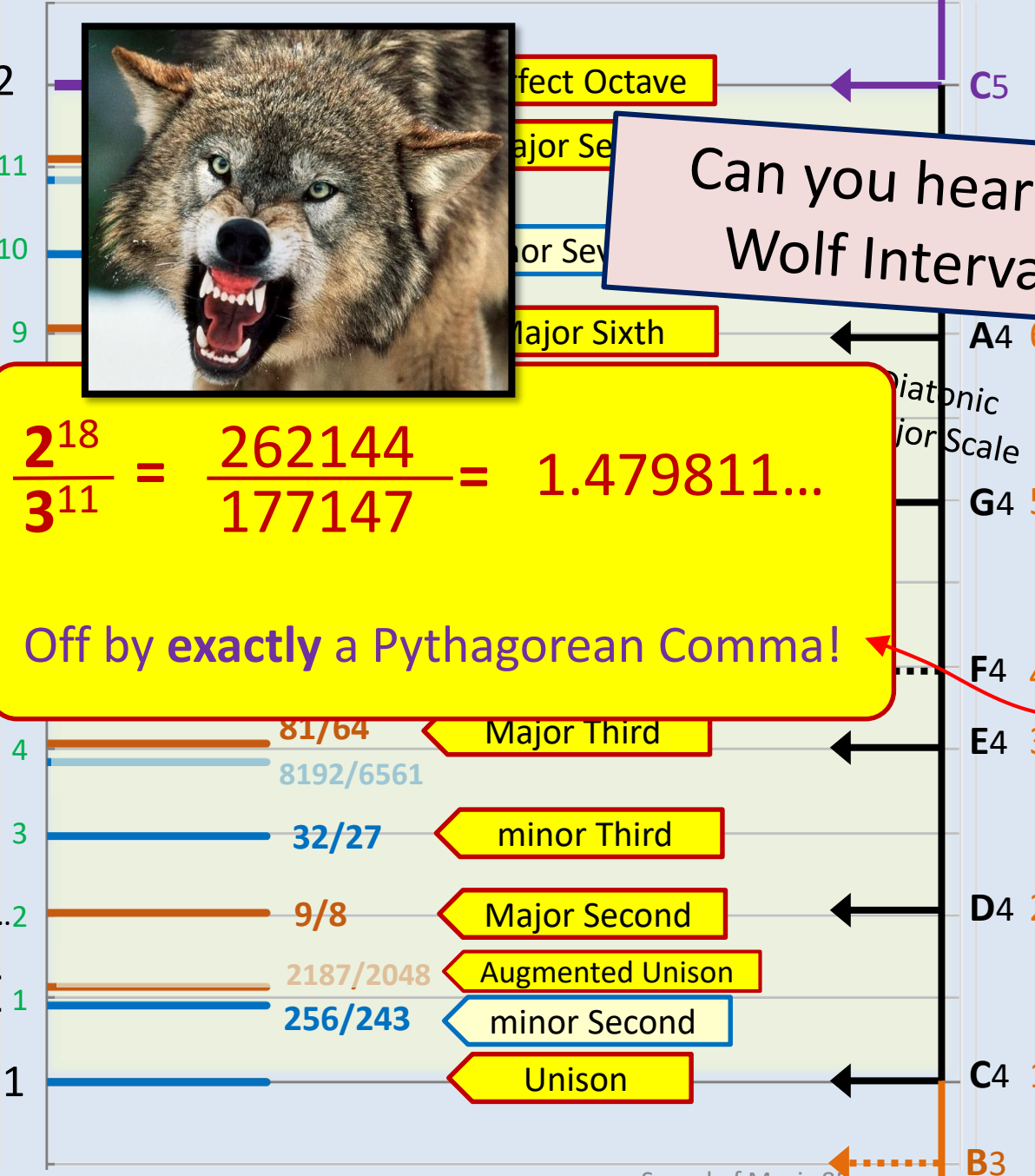


Can you hear the Wolf Interval?

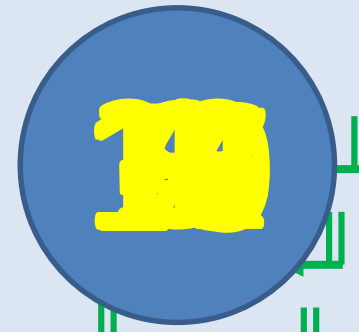
$\frac{2^{18}}{3^{11}} = \frac{262144}{177147} = 1.479811\dots$

Off by **exactly** a Pythagorean Comma!

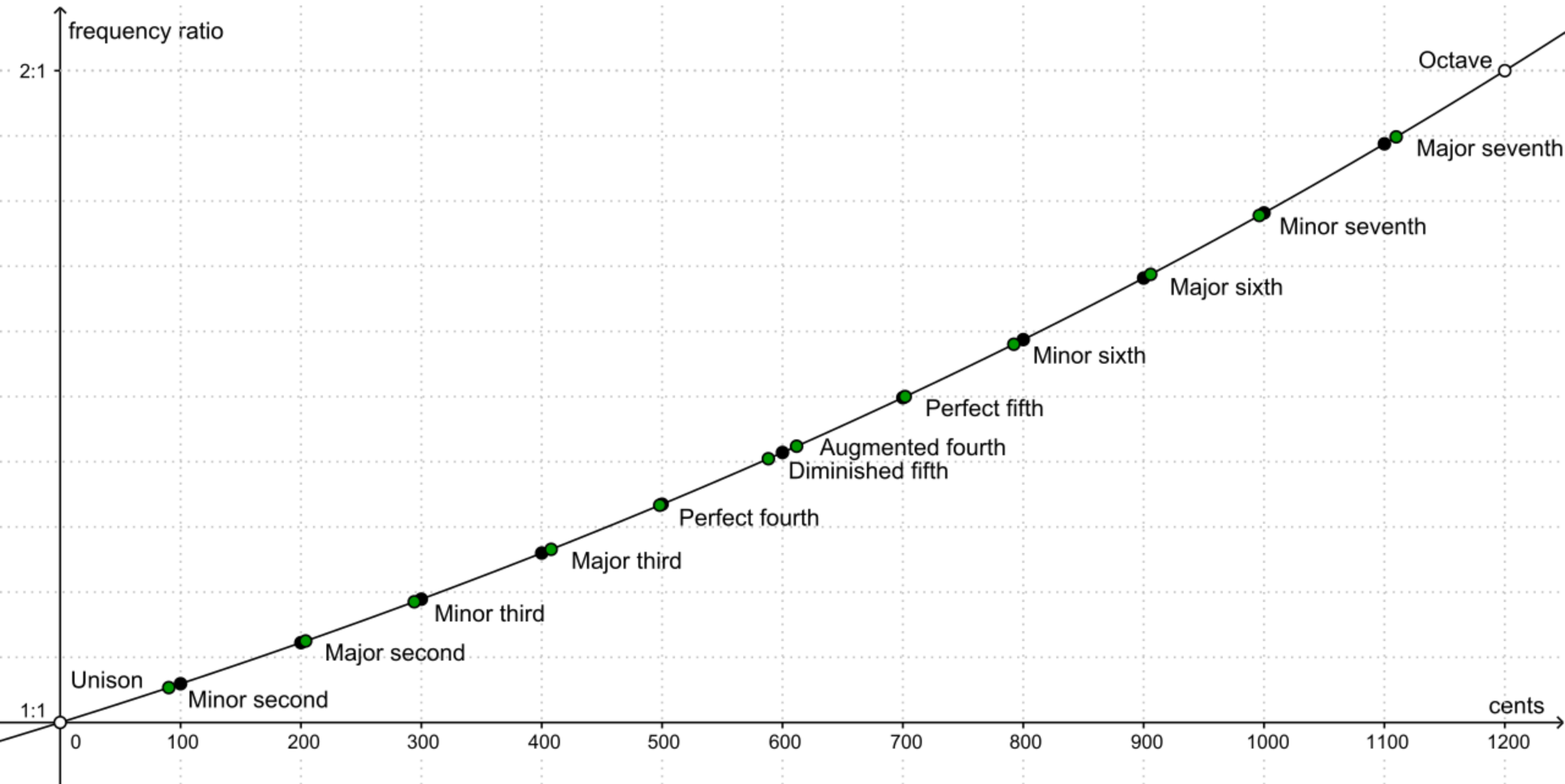
Frequency (log) ↑



Pythagorean Comma (Euclid)
 $\frac{531441}{524288} \approx 1.01364\dots$



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



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)
 - 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

Comparison of Alternative Tuning Schemes and Temperaments

12 Notes per Octave

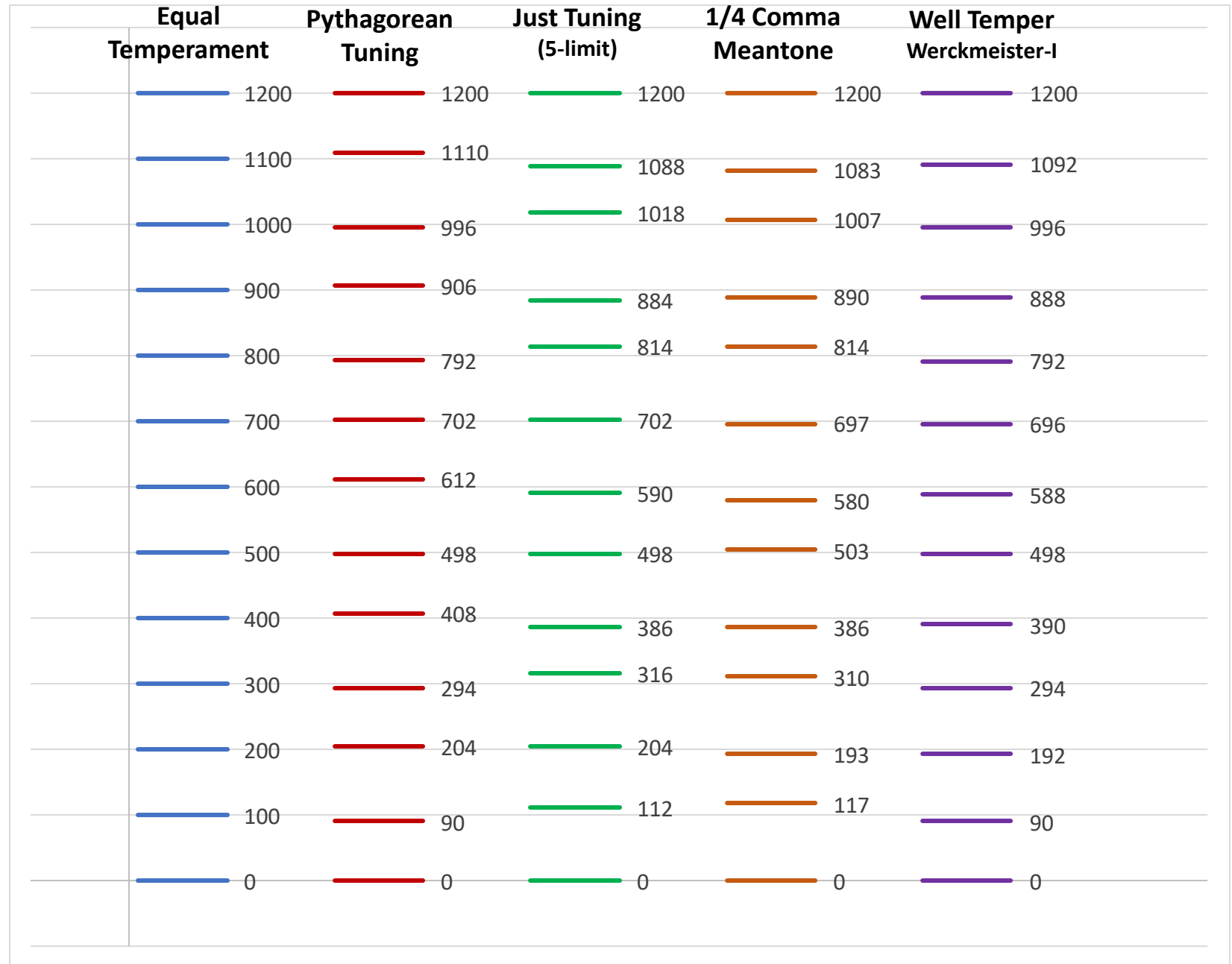
Log Frequency Scale

Notes labeled with ratios to base frequency

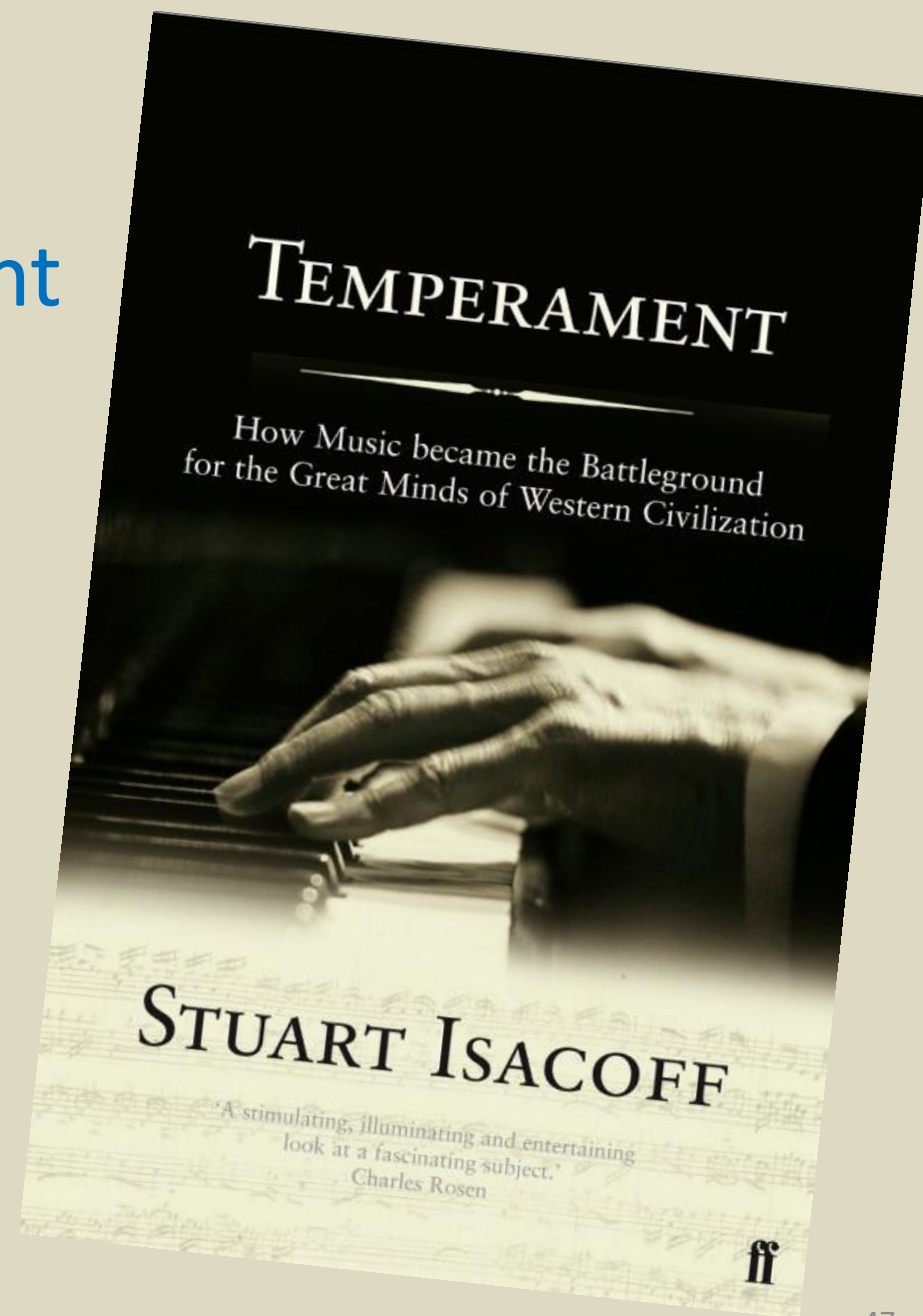
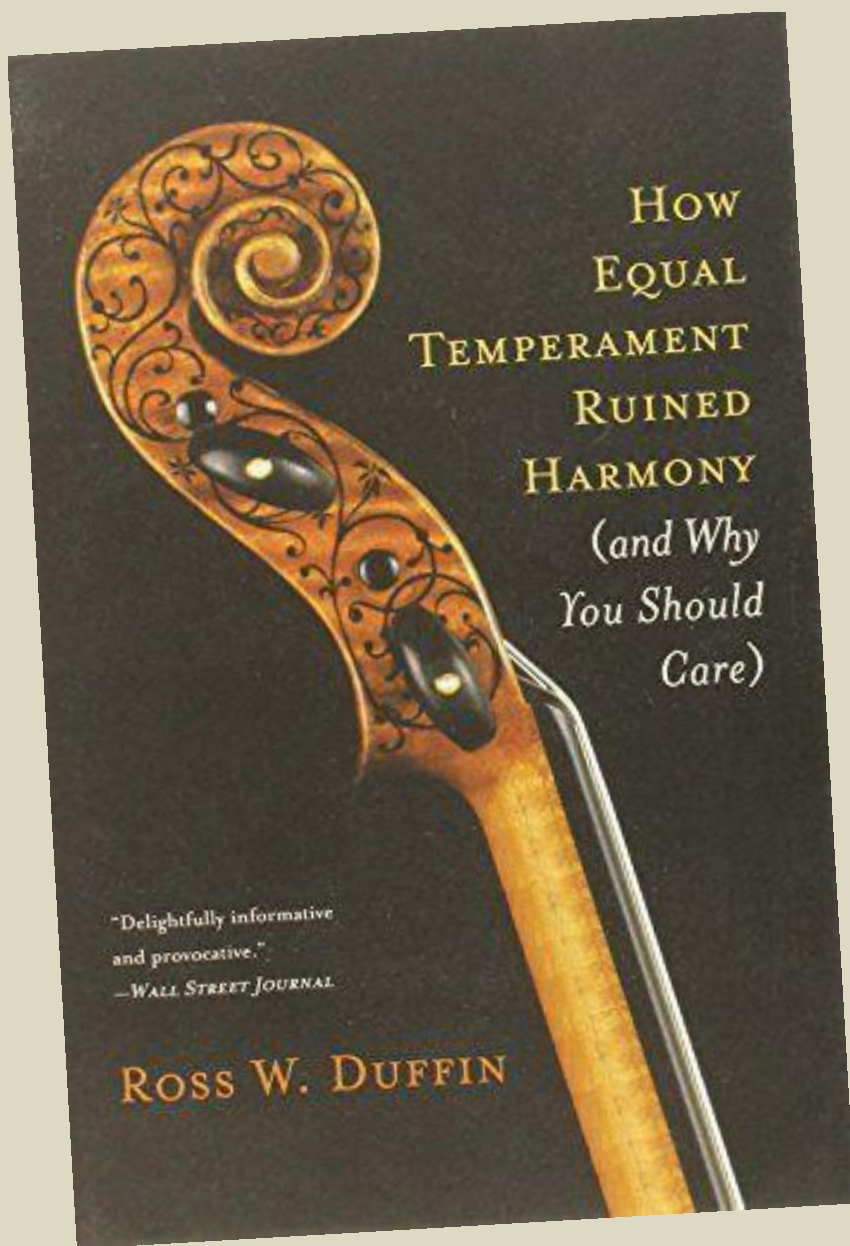
	Equal Temperament	Pythagorean Tuning	Just Tuning (5-limit)	1/4 Comma Meantone	Well Temper Werckmeister-I
	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>
	<u>1.888</u>	<u>243/128</u>	<u>15/8</u>	<u>1.8694</u>	<u>1.879</u>
	<u>1.782</u>	<u>16/9</u>	<u>9/5</u>	<u>1.789</u>	<u>1.778</u>
	<u>1.682</u>	<u>27/16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

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)



The Temperament Wars



Split Key Harpsichord: 19 Notes per Octave

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



Christopher Stembidge
on CD
Consonanze Stravaganti
(2000)

Modern reproduction of 1631 Italian Faber Instrument

Denzil Wraight

Names of Intervals

Number of semitones	Minor, major, or perfect intervals	Short	Augmented or diminished intervals	Short	Widely used alternative names
0	Perfect unison	P1	Diminished second	d2	
1	Minor second	m2	Augmented unison	A1	Semitone, half tone, half step
2	Major second	M2	Diminished third	d3	Tone, whole tone, whole step
3	Minor third	m3	Augmented second	A2	
4	Major third	M3	Diminished fourth	d4	
5	Perfect fourth	P4	Augmented third	A3	
6			Diminished fifth	d5	Tritone
			Augmented fourth	A4	
7	Perfect fifth	P5	Diminished sixth	d6	
8	Minor sixth	m6	Augmented fifth	A5	
9	Major sixth	M6	Diminished seventh	d7	
10	Minor seventh	m7	Augmented sixth	A6	
11	Major seventh	M7	Diminished octave	d8	
12	Perfect octave	P8	Augmented seventh	A7	