





# An Ear for Music

## How It Works

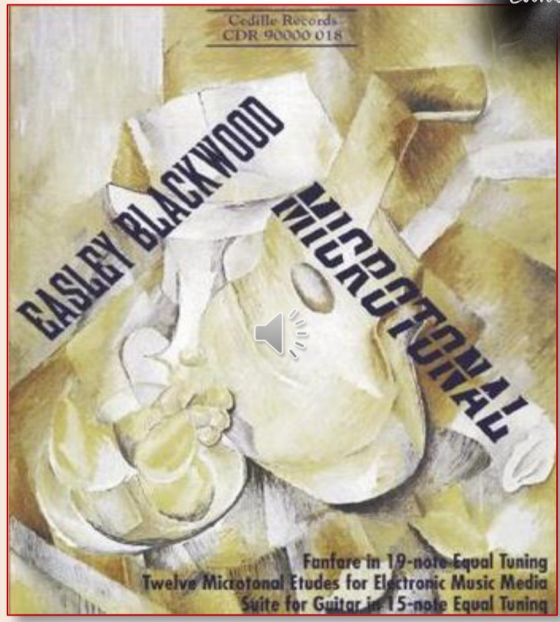
### Session 4

### Musical Scales

OLLI at Illinois

Spring 2024

D. H. Tracy



Easley Blackwood

*Twelve Microtonal Etudes*

*Op 28 (1980)*

13 Notes/Octave

(Sostenuto)







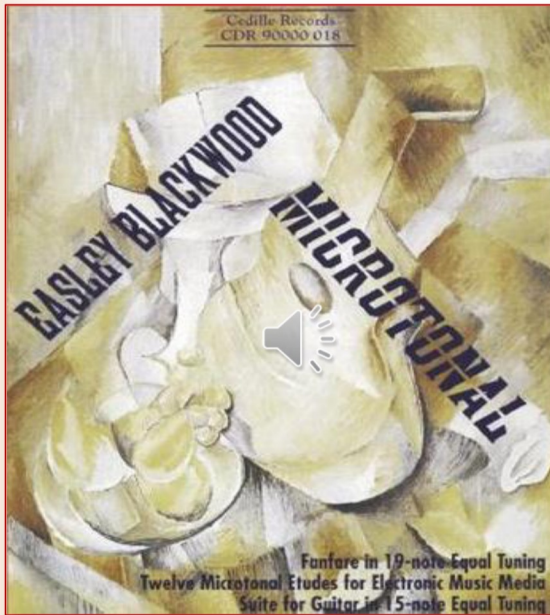
# An Ear for Music

## How It Works

### Session 4 Musical Scales

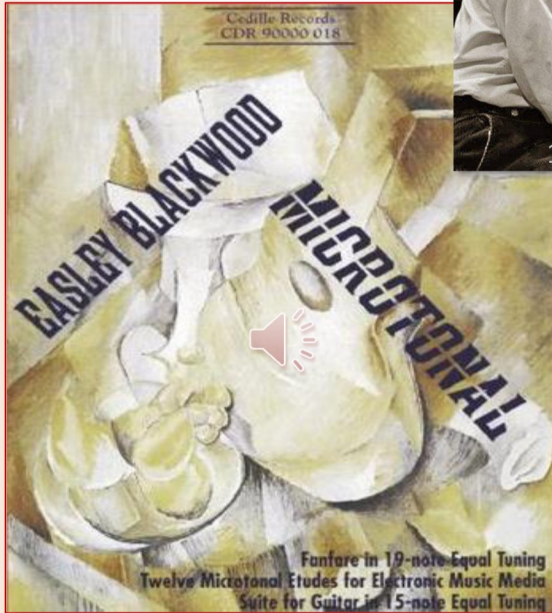
OLLI at Illinois  
Spring 2024

D. H. Tracy



Easley Blackwood  
*Twelve Microtonal Etudes*  
*Op 28 (1980)*  
17 Notes (Con moto)





Easley Blackwood  
*Suite for Guitar*  
*in 15-note Equal Tuning,*  
*Op. 33*  
Jeffrey Kust, guitarist  
(1990)

# An Ear for Music

## How It Works

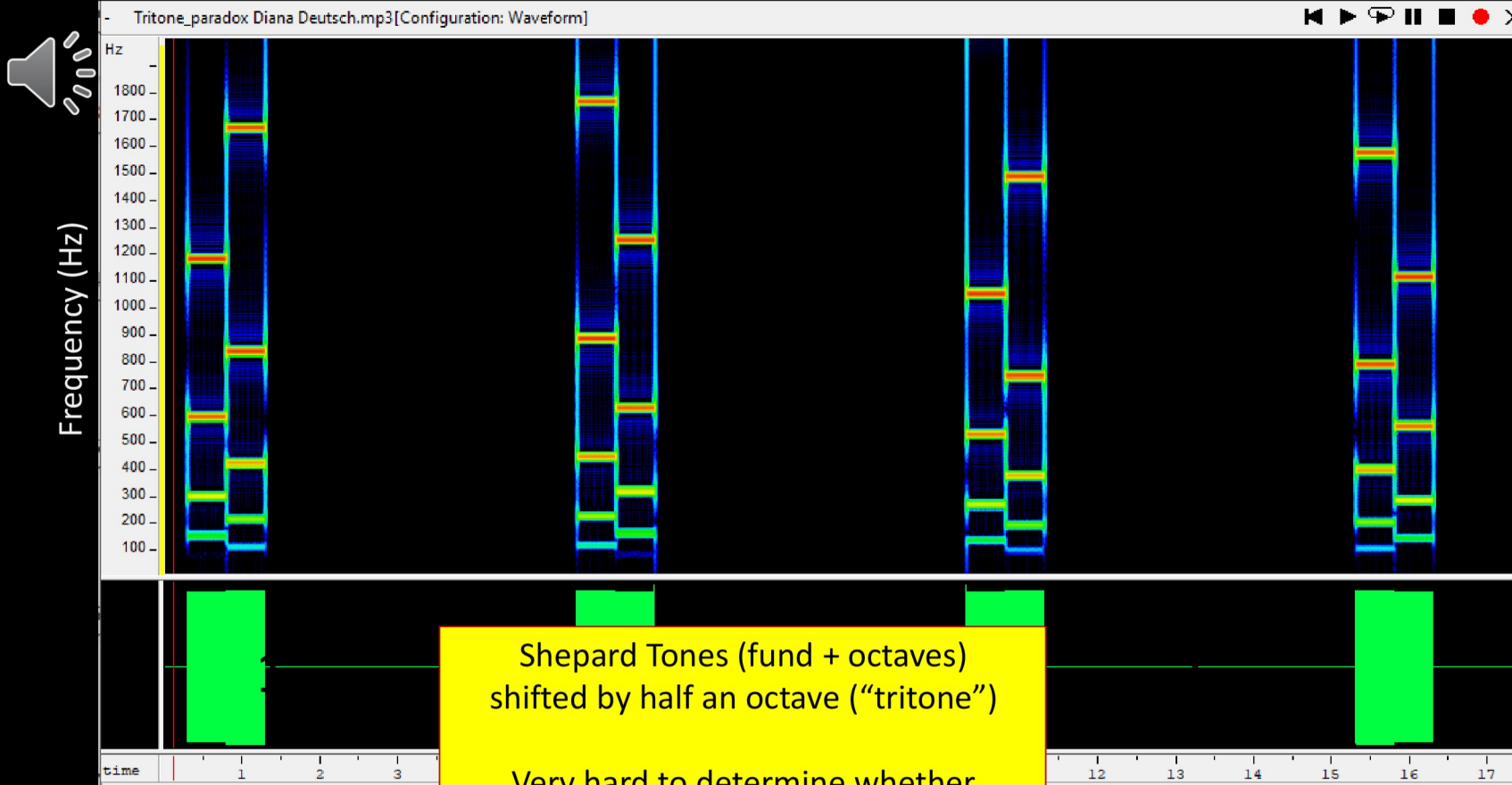
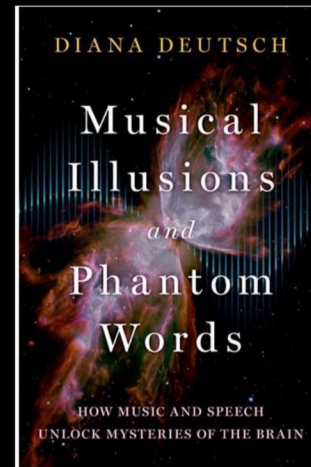
Session 4  
Musical Scales

OLLI at Illinois  
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D. H. Tracy



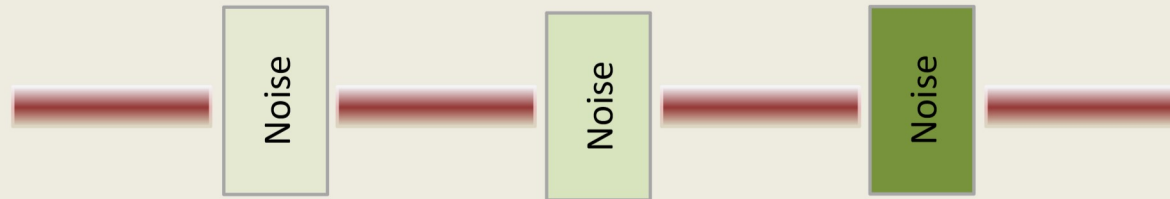
# Diana Deutsch's Tritone Paradox





# Continuity Illusion

Series of beeps...



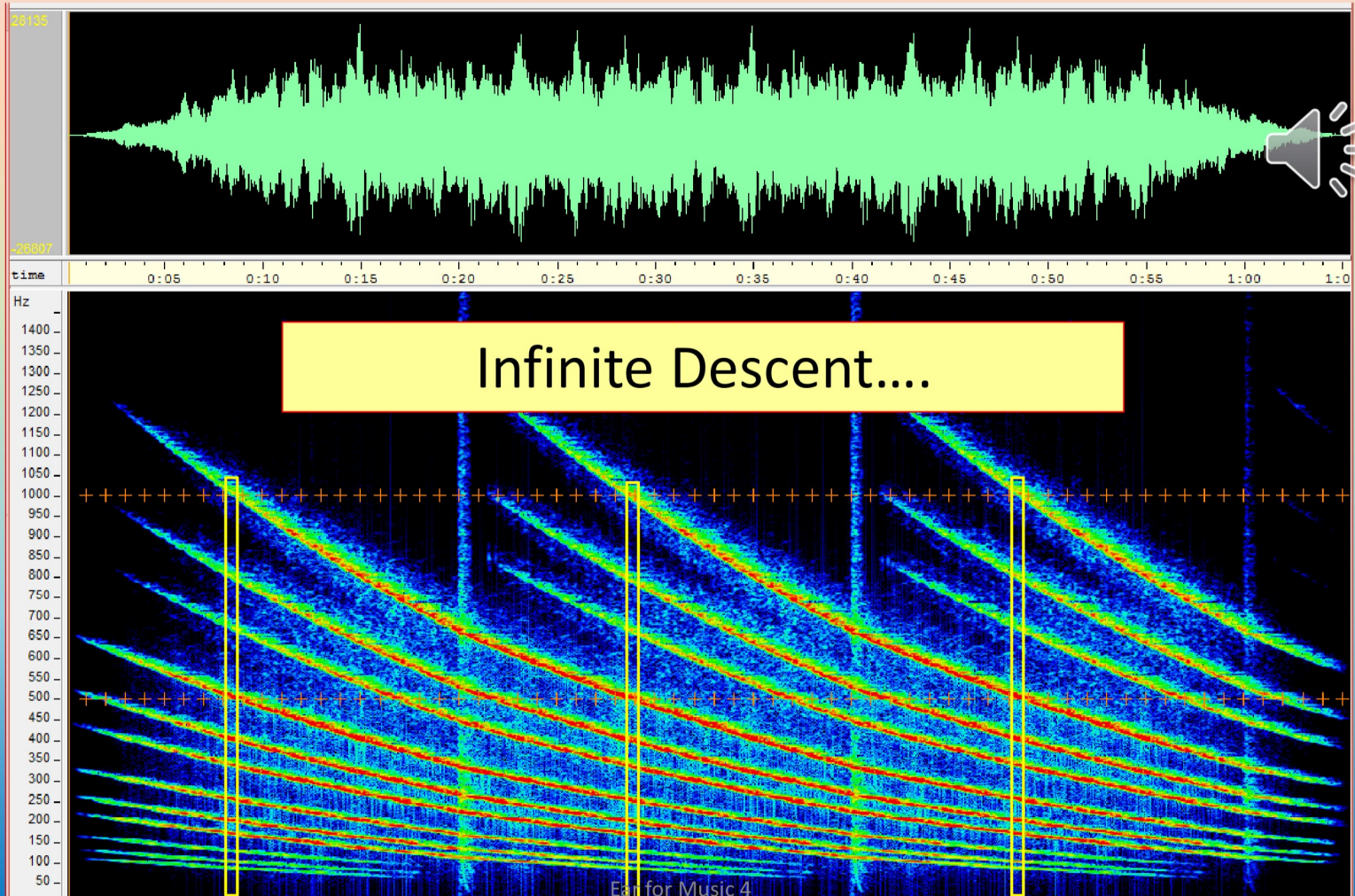
Now concentrate on the beeps...

**Ignore the noise**

The beeps merge into one continuous tone when masked by noise

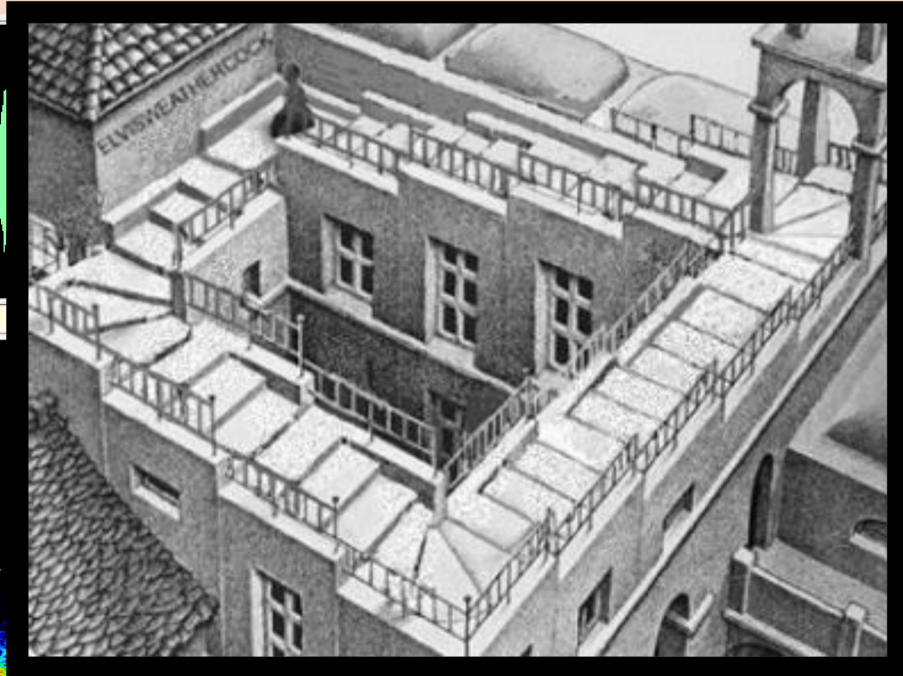
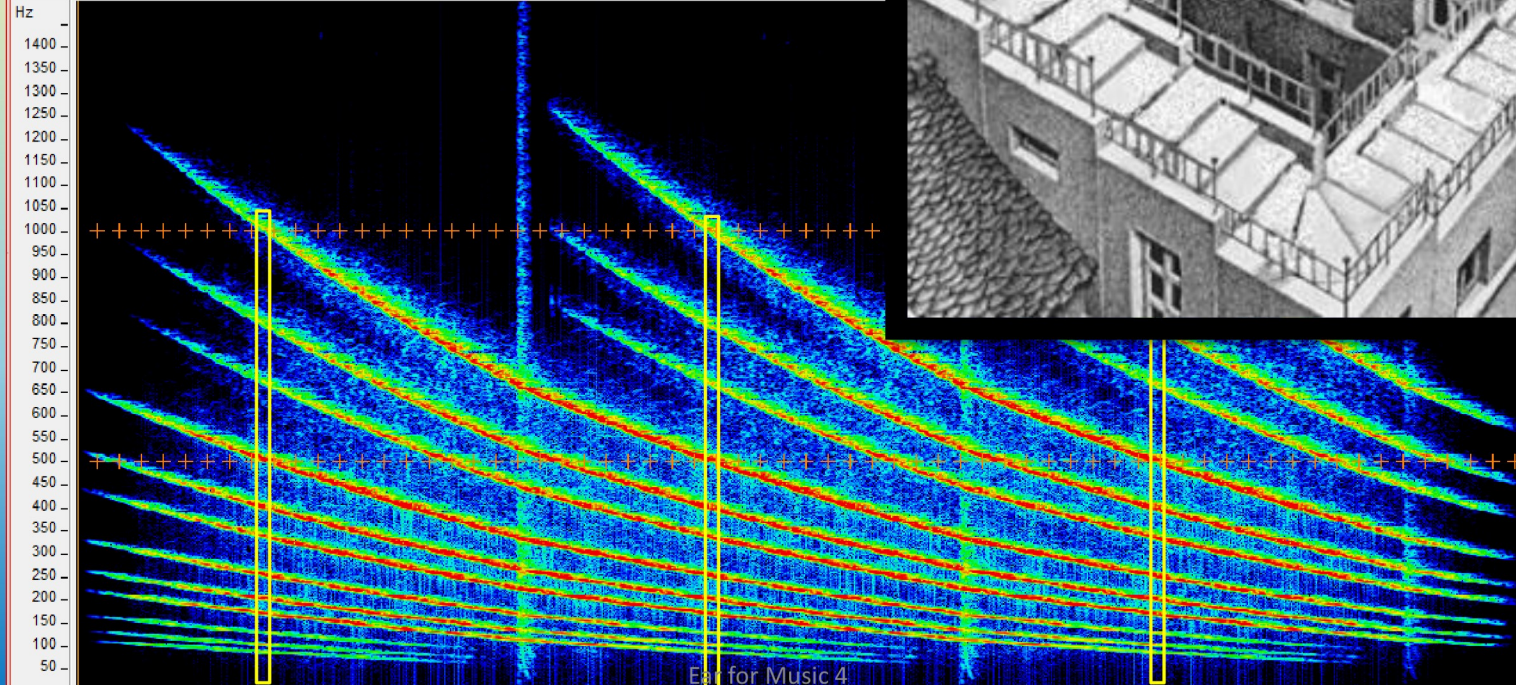
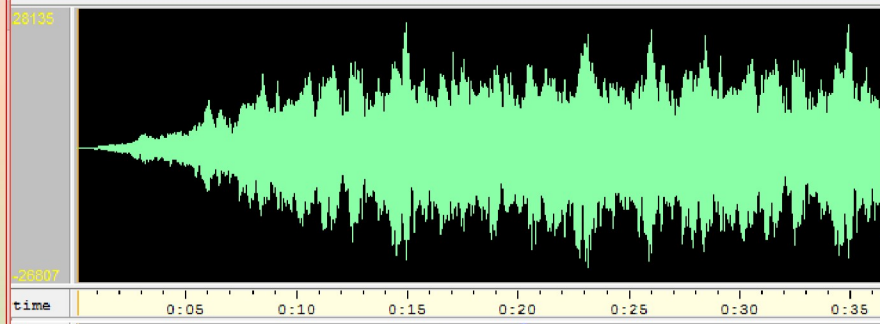


# Shepard-Risset Glissando



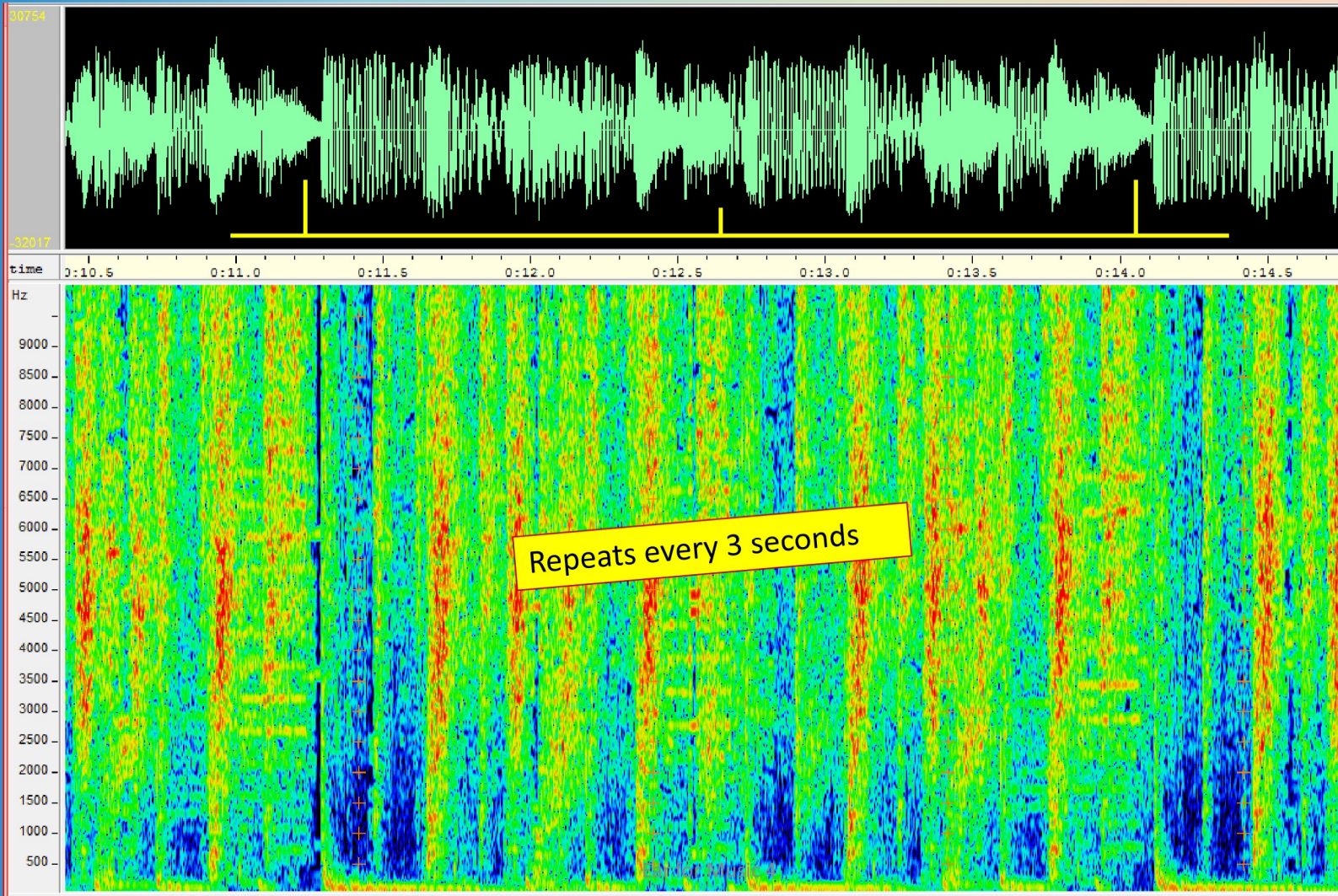


# Shepard-Risset Glissando





# Risset's Accelerando



# Course Outline



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

## Question Times



- Zoomland
- In Person

- Halfway Through
- At the End





# Sound Familiar?



- Listen carefully to 4 notes
  - 2 are “real”, 2 are “bogus”
  
- In isolation, it makes little difference...
  - but in the context of a musical piece it may matter



# Music is Made with Notes Having Different Frequencies

- But how are these frequencies chosen?

- Example using Fixed Frequencies...



- But what if we used random frequencies?

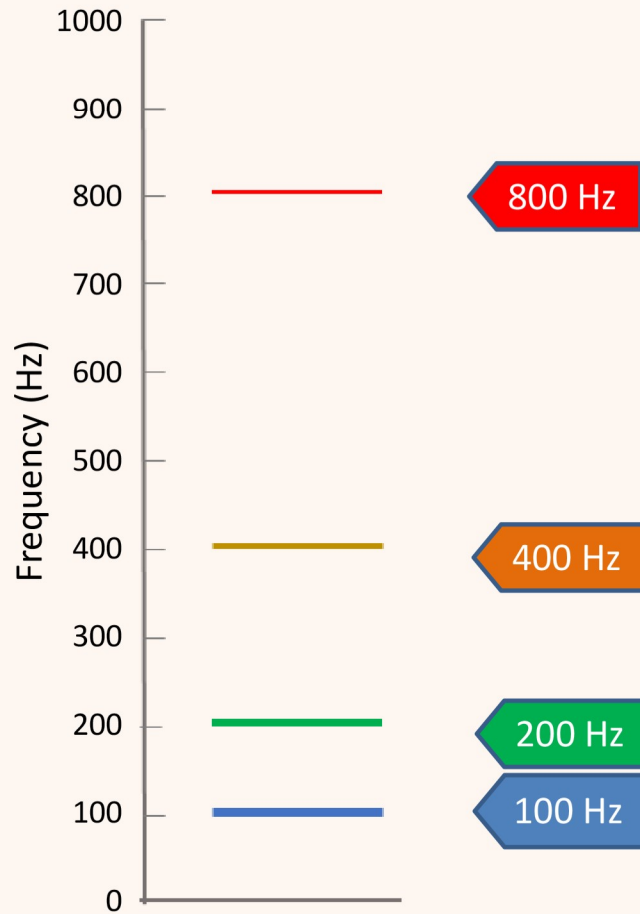


– Each note frequency chosen at *random*

- ***Music can be made with non-fixed frequencies***



# The Octave As the Universal Frequency Interval *2x*

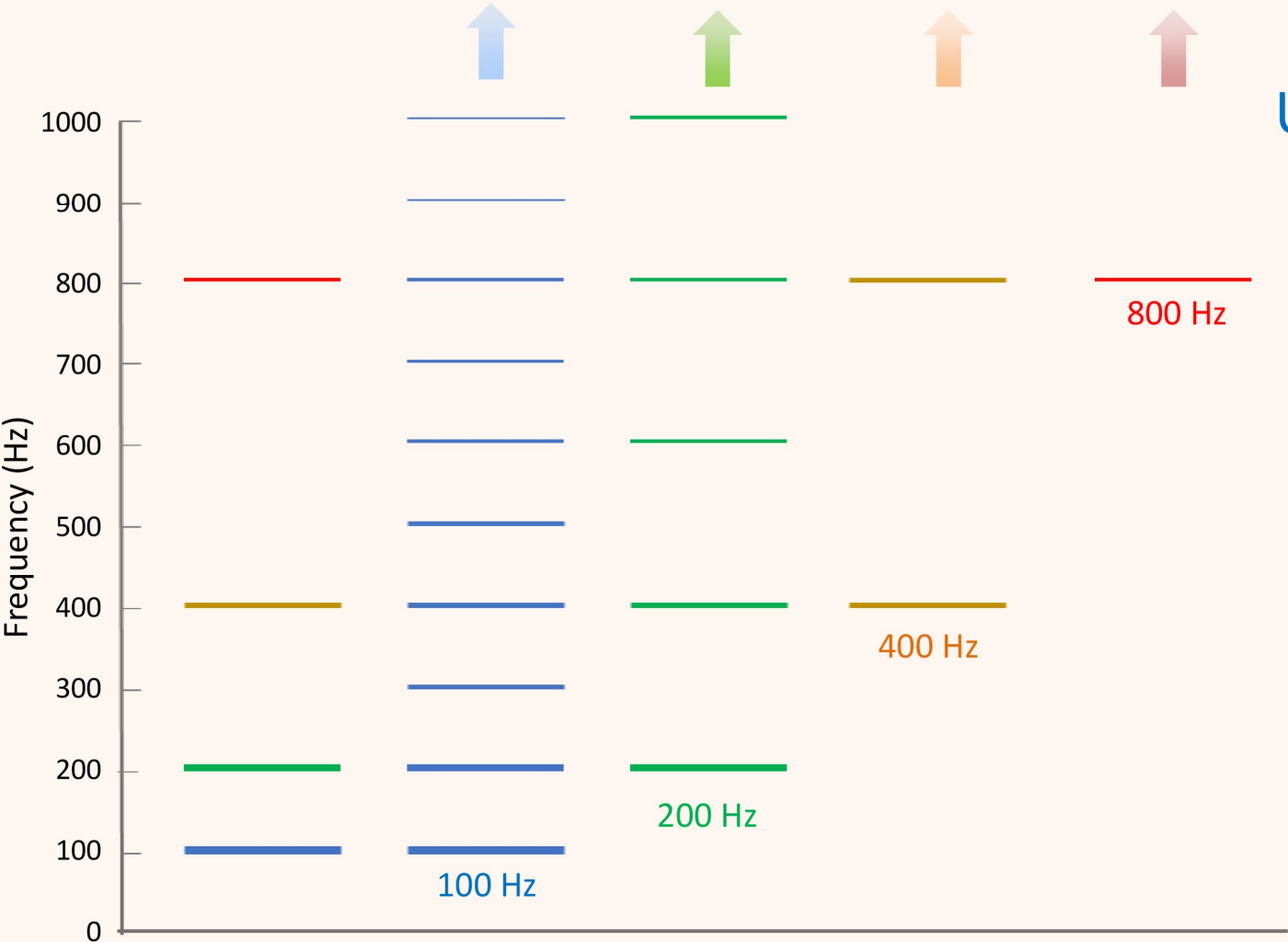


But these were  
Complex Tones  
with 16 Harmonics....





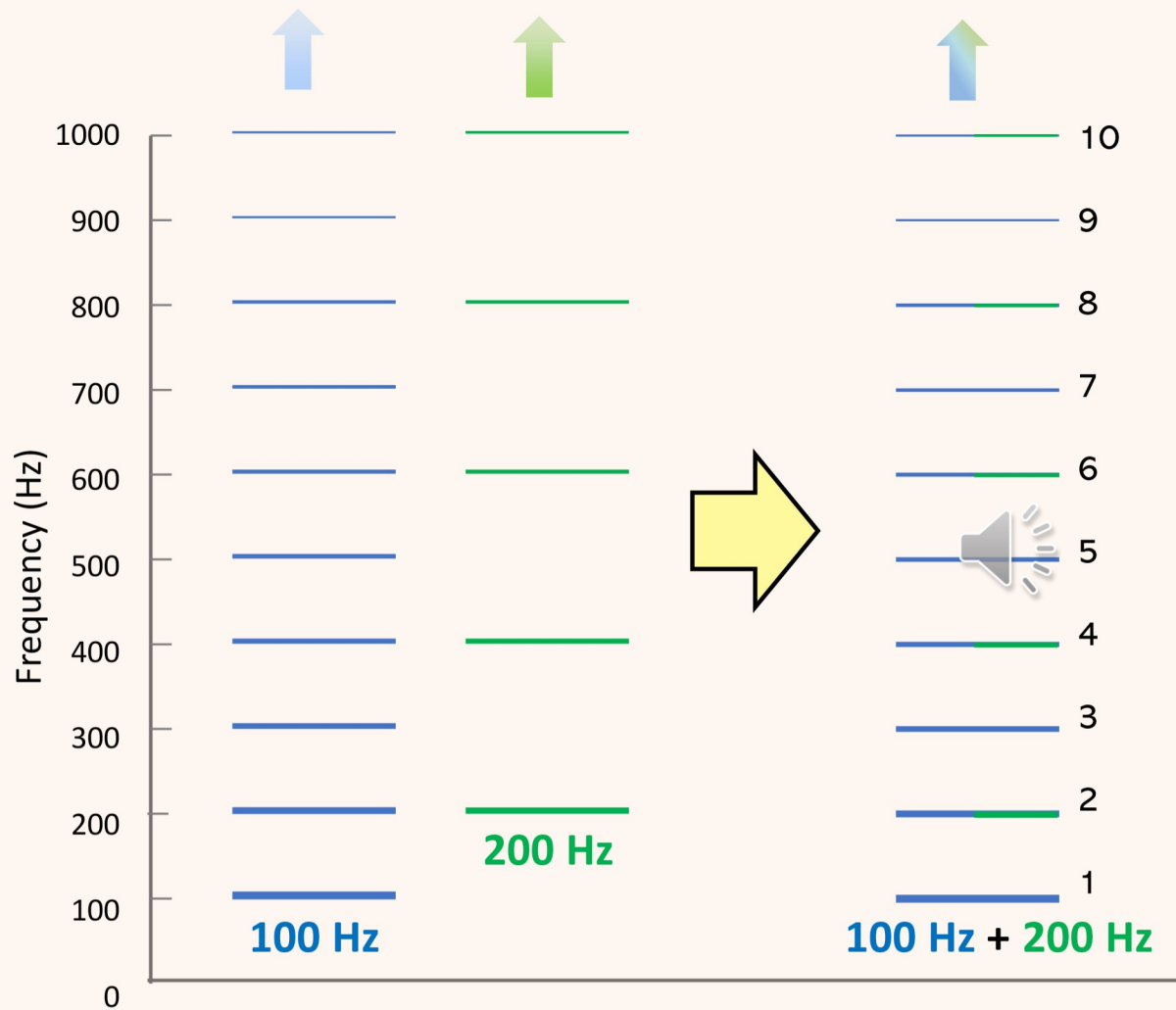
# The Octave As the Universal Frequency Interval $2x$



Higher Octaves Contain NO additional frequencies!

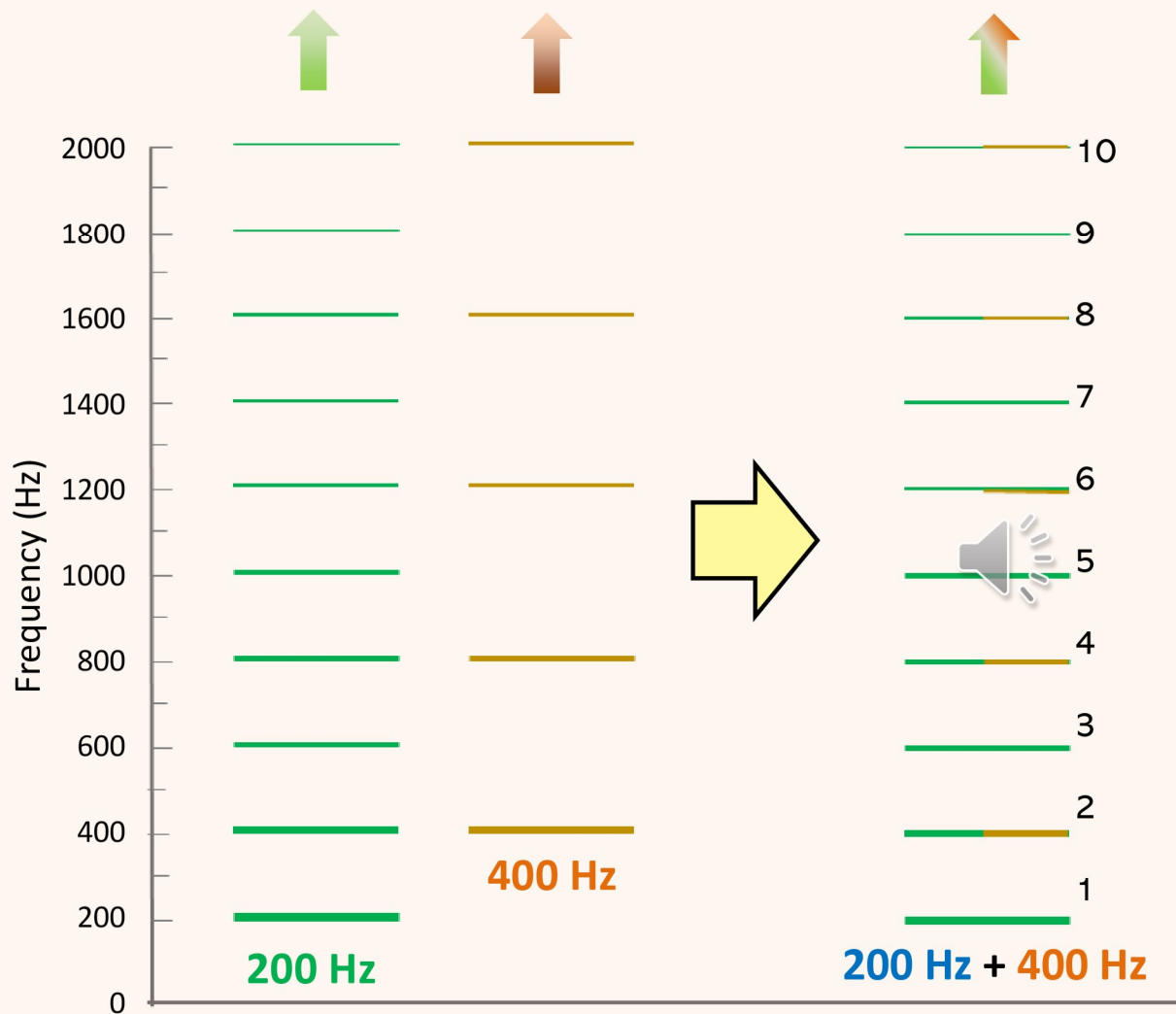


# The Octave As the Universal Frequency Interval $2x$



- The Combination of  $f$  and its octave sounds good
- The Combination  $f + 2f$  sounds a lot like  $f$  alone

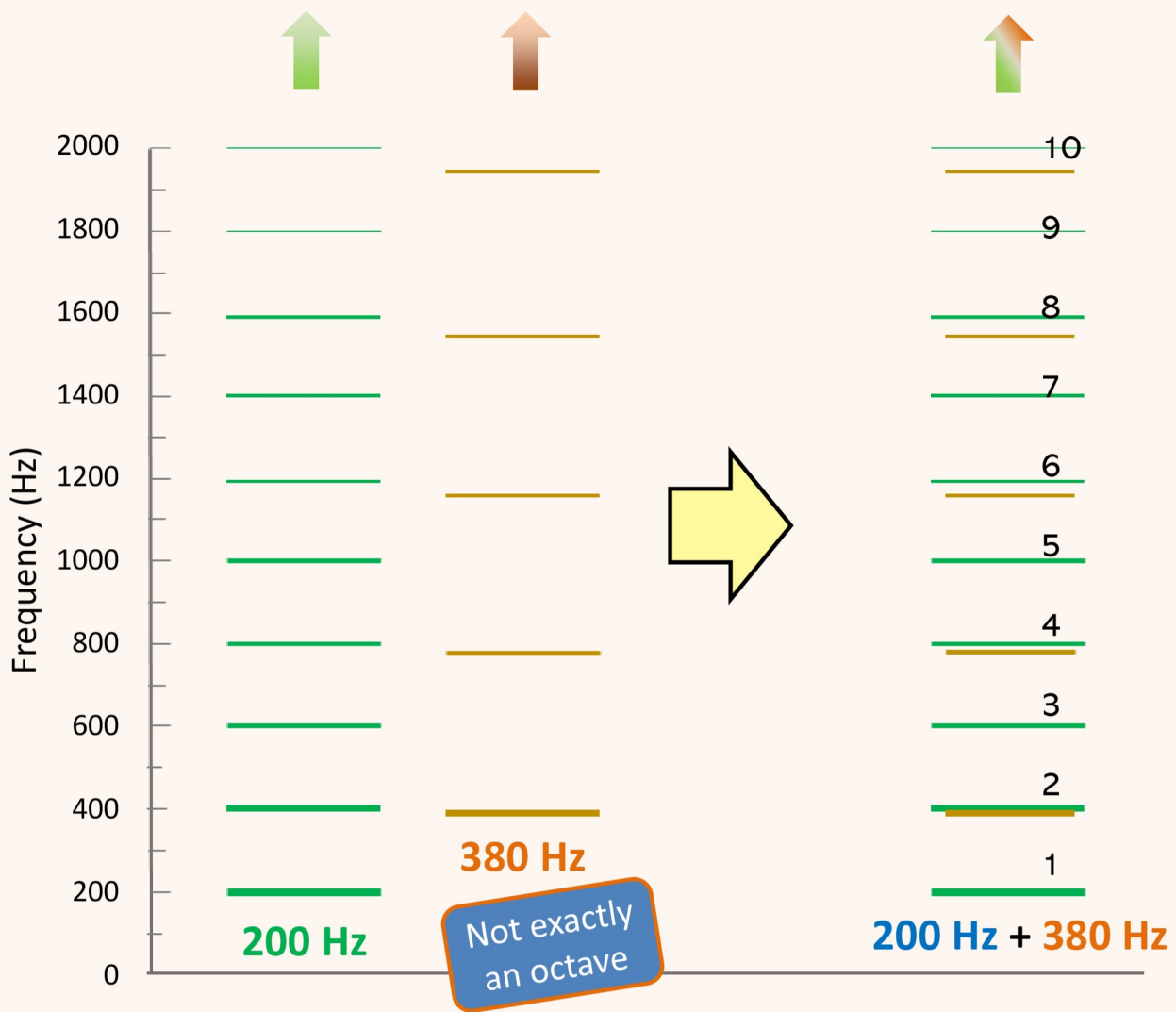
# The Octave As the Universal Frequency Interval $2x$



- Again, the Combination of  $f$  and its octave sound good
- The Combination  $f + 2f$  sounds somewhat like  $f$  alone



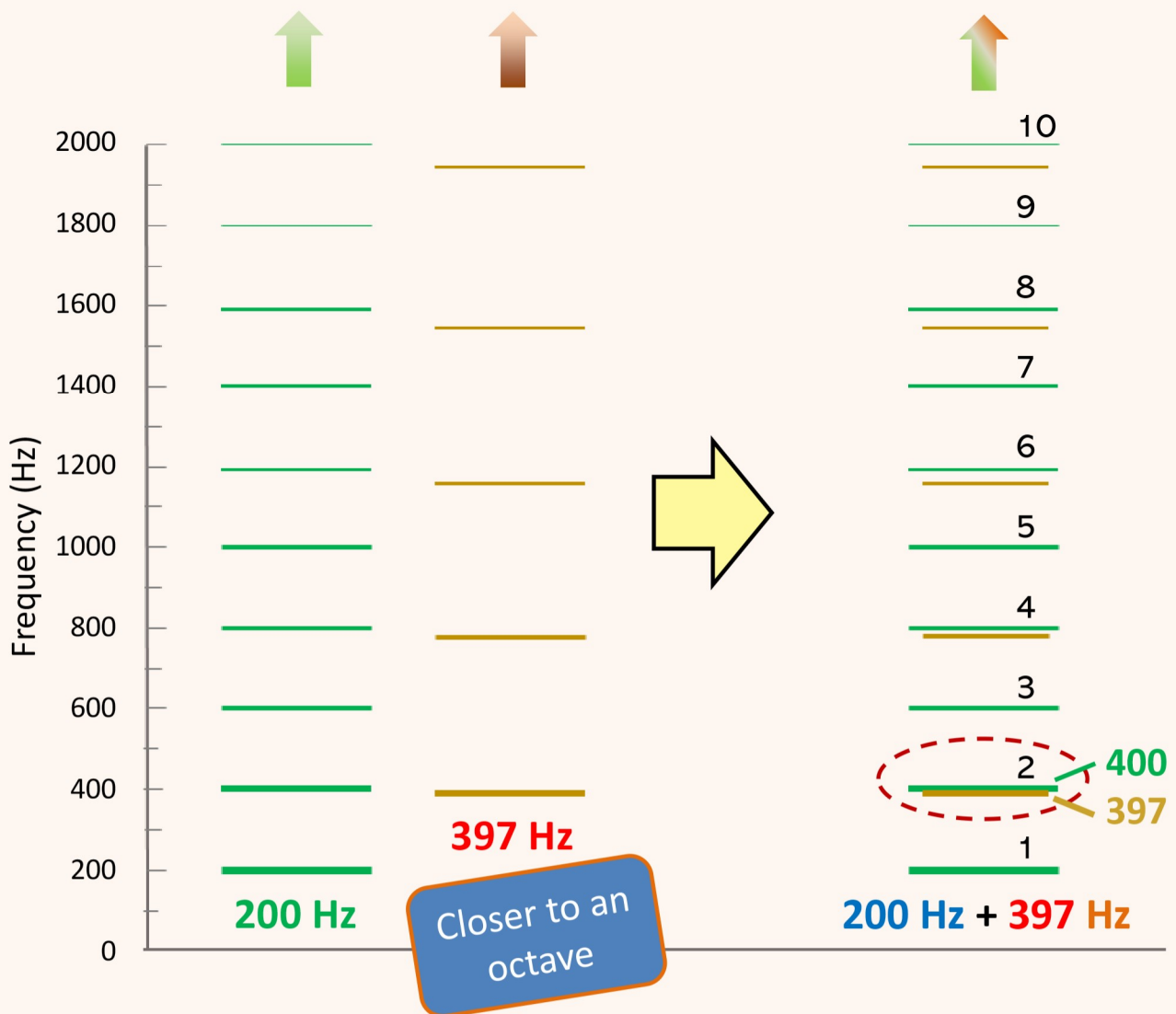
# The Octave As the Universal Frequency Interval $2x$



- The Combination of  $f$  and its not-quite-octave sounds terrible



# The Octave As the Universal Frequency Interval $2x$

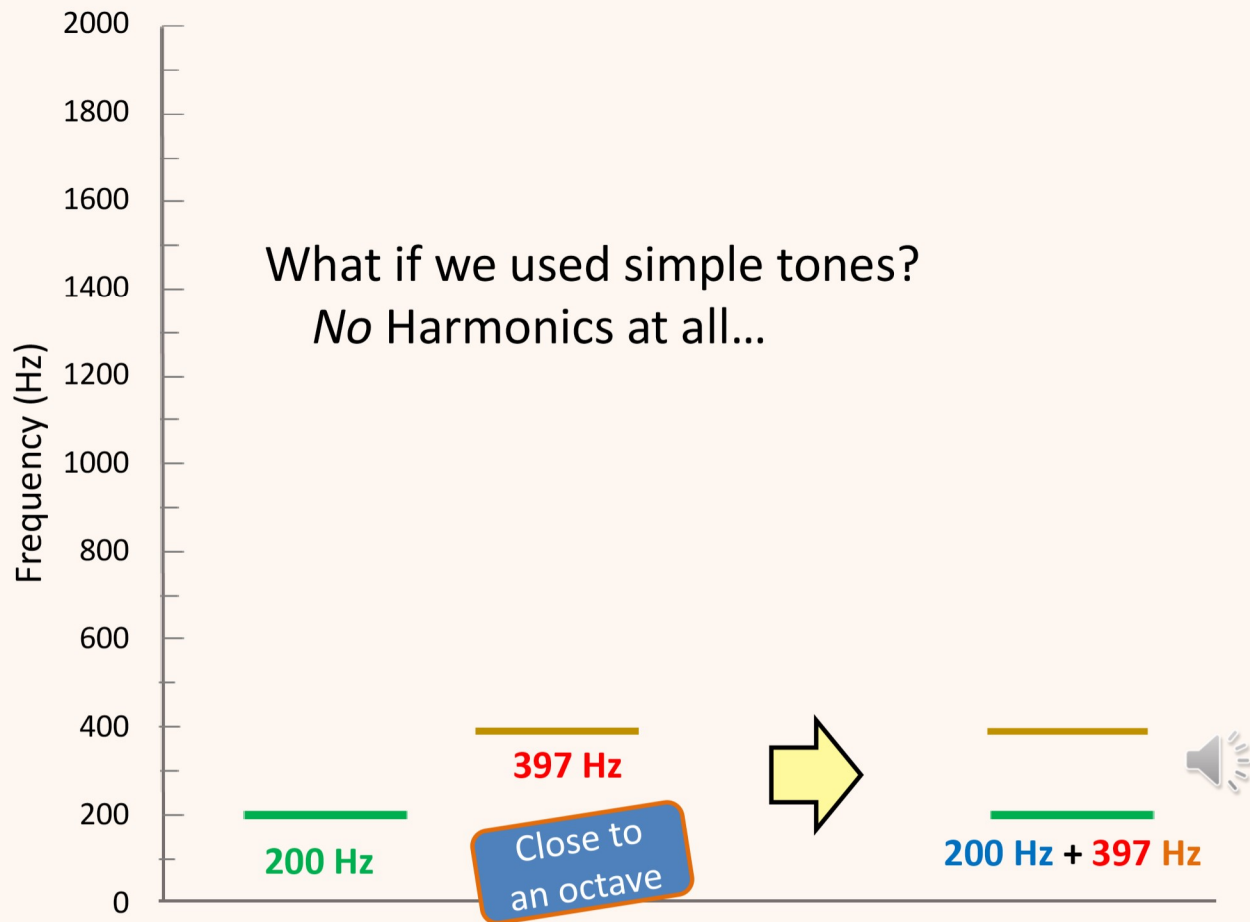


If we are close to an Octave, we can hear the beats



# The Octave As the Universal Frequency Interval $2x$

What if we used simple tones?  
No Harmonics at all...



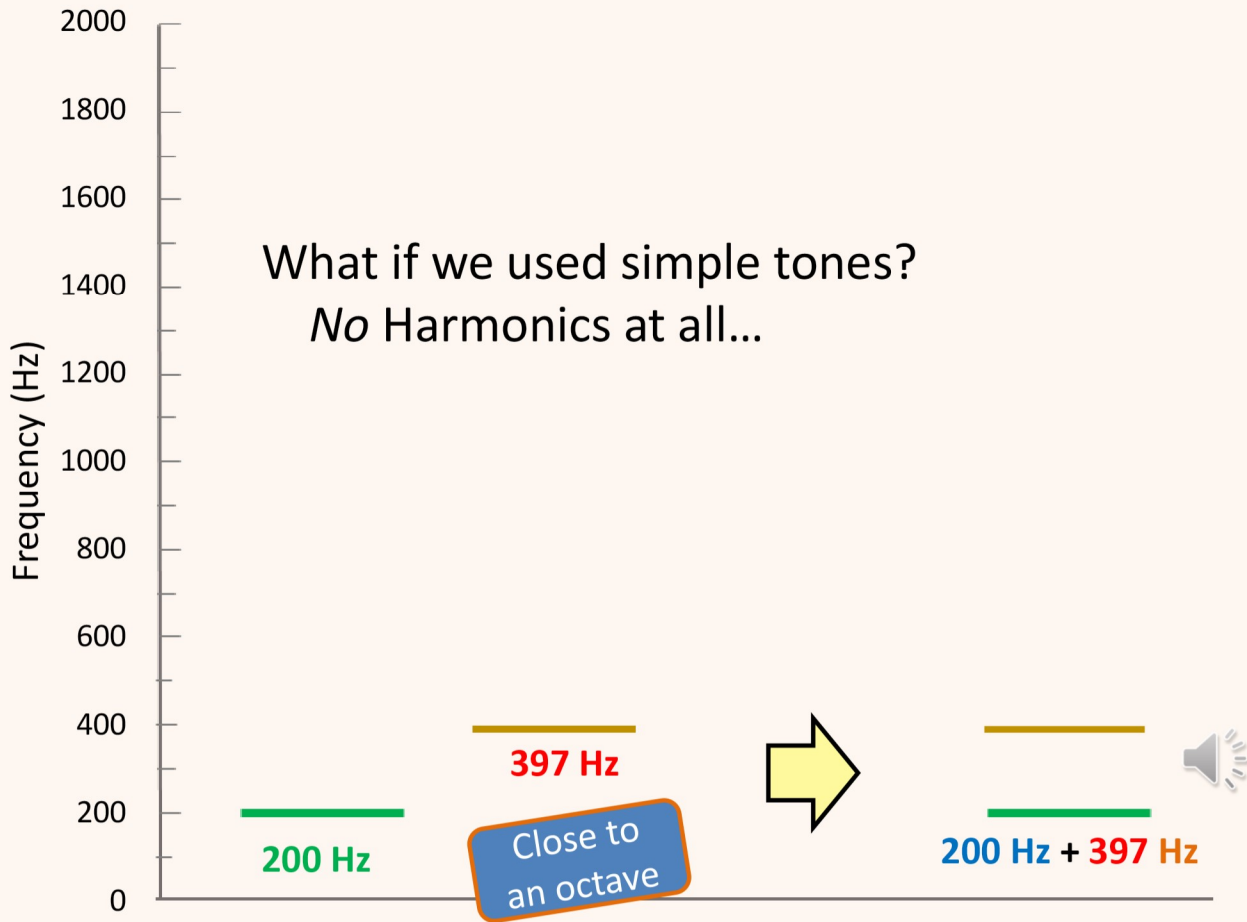
- Without Harmonics,  
Nothing Special  
about the Octave





# The Octave As the Universal Frequency Interval $2x$

What if we used simple tones?  
No Harmonics at all...



- Without Harmonics, Nothing Special about the Octave

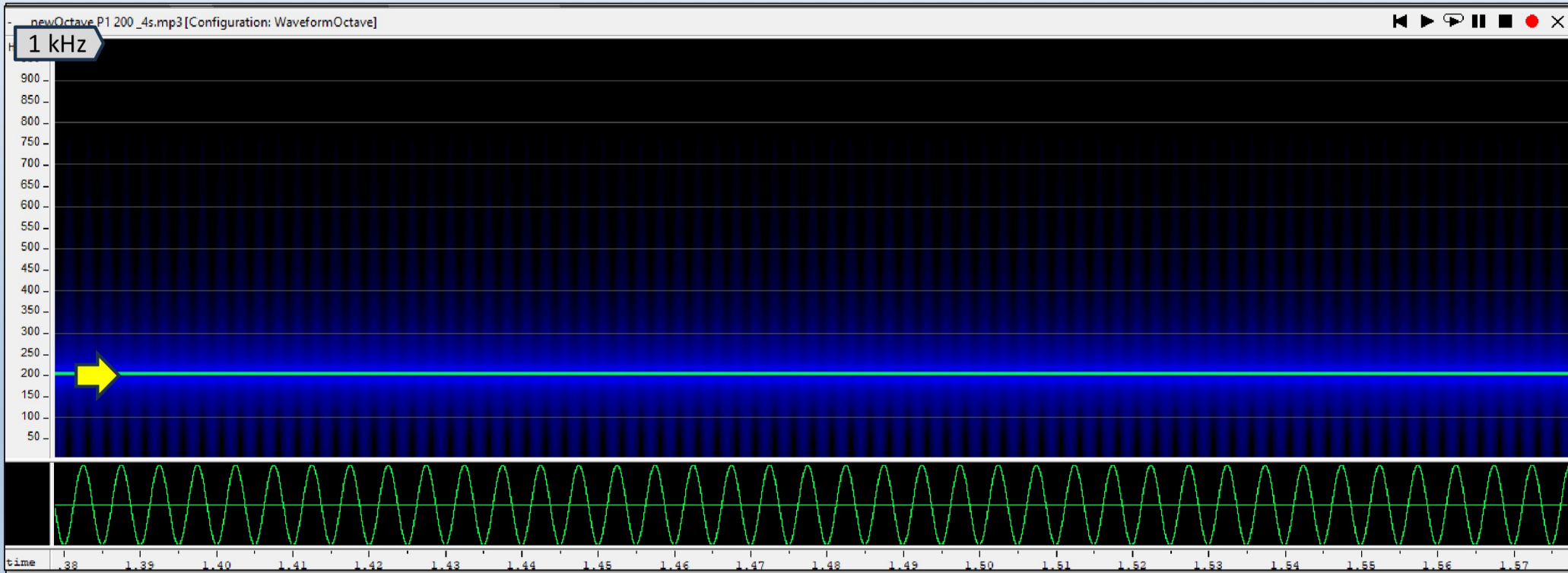
But we did hear beats, albeit faintly

Dirty little secret of sound reproduction:

Speakers <sup>usually</sup> ~~often~~ fail to faithfully reproduce waveforms. They make stuff up.

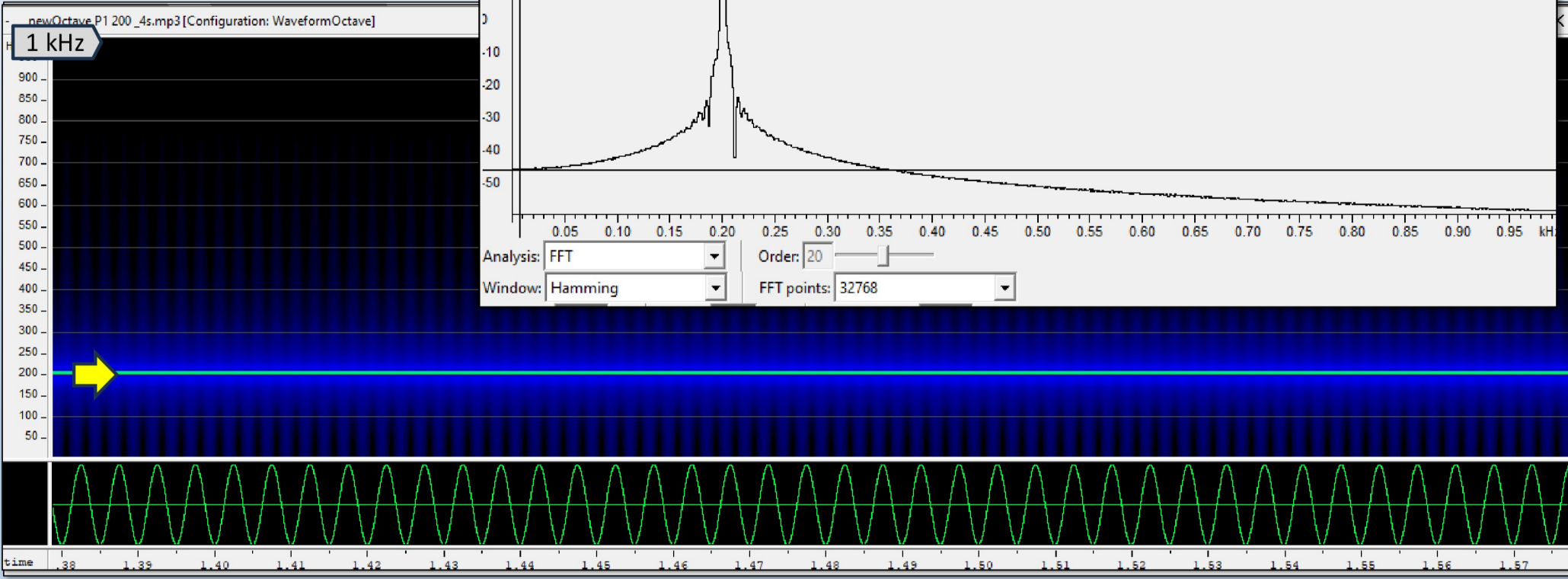


# 200 Hz Pure Tone as presented to Loudspeakers





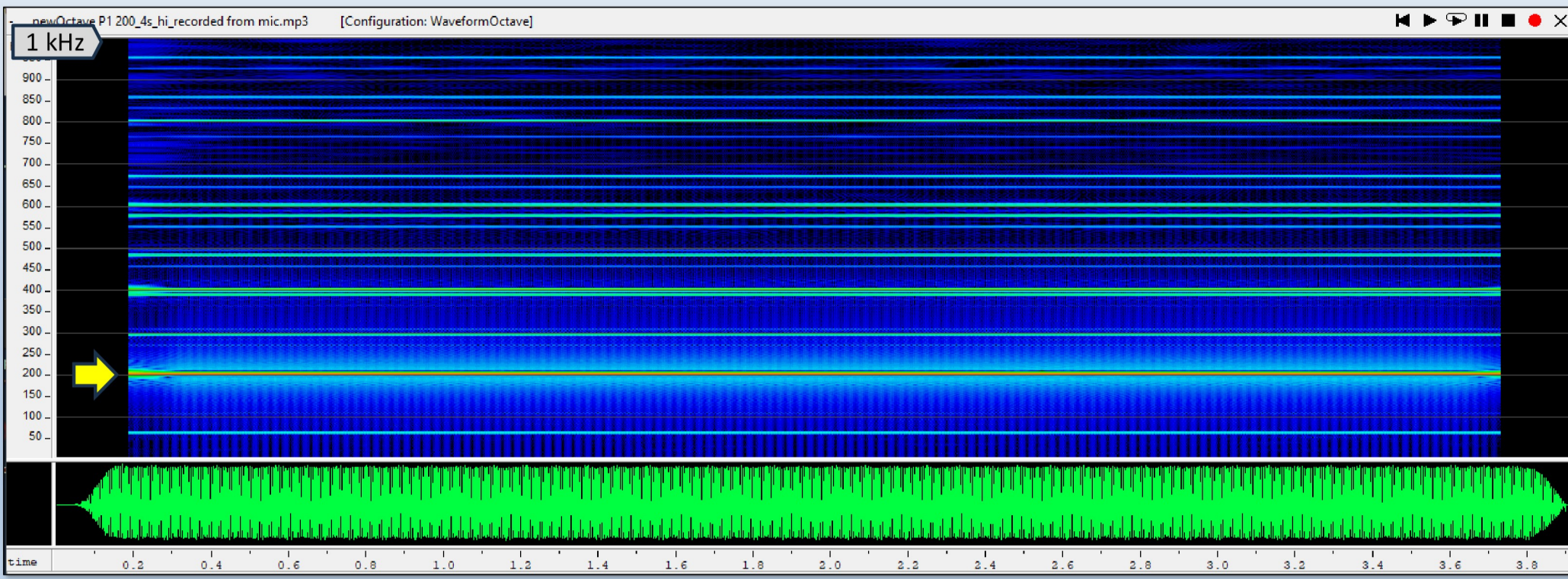
# 200 Hz Pure Tone as presented to Loudspeakers



# 200 Hz Pure Tone as *Heard* Through Imperfect Loudspeakers!



This is the sound heard on  
my Speakers at home

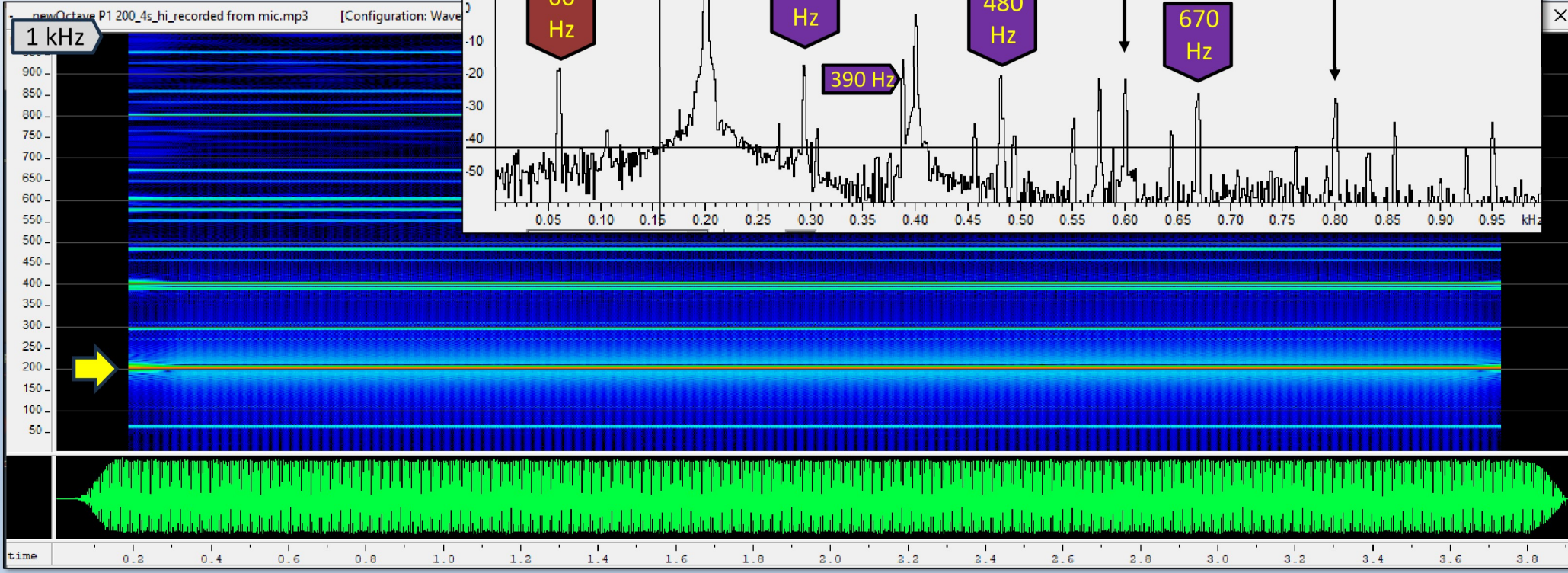
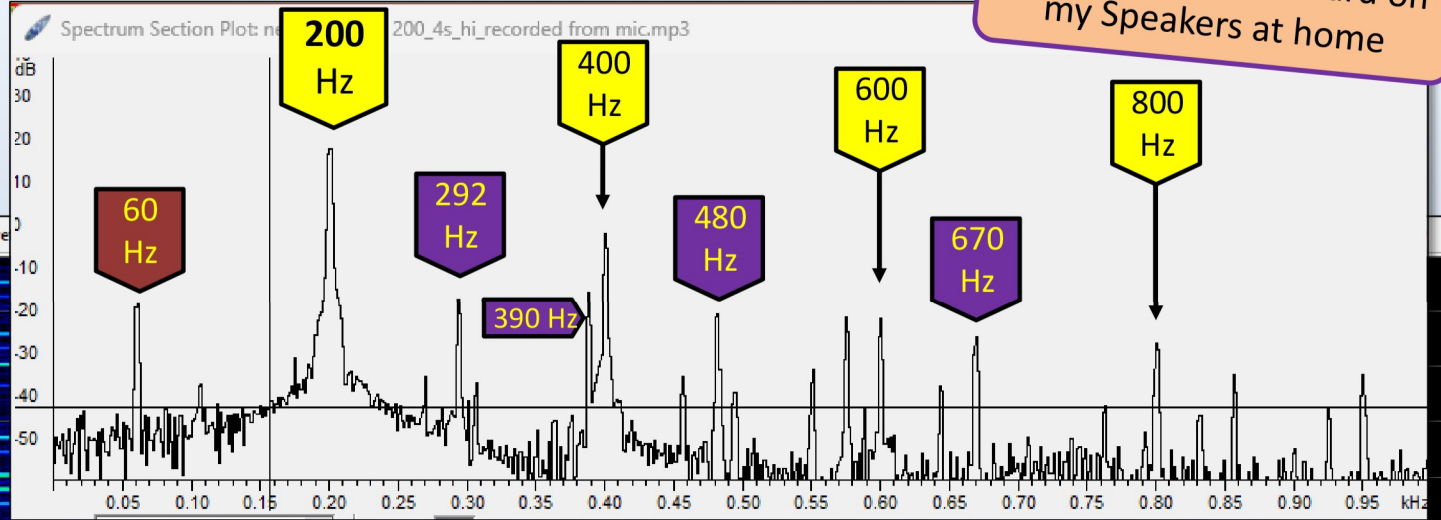




# 200 Hz Pure Tone as Heard Through Imperfect Loudspeakers!

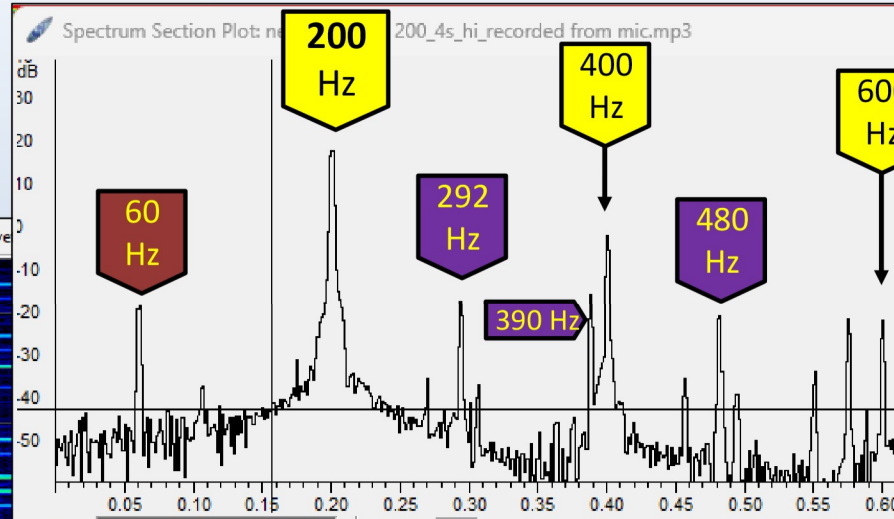


This is the sound heard on my Speakers at home

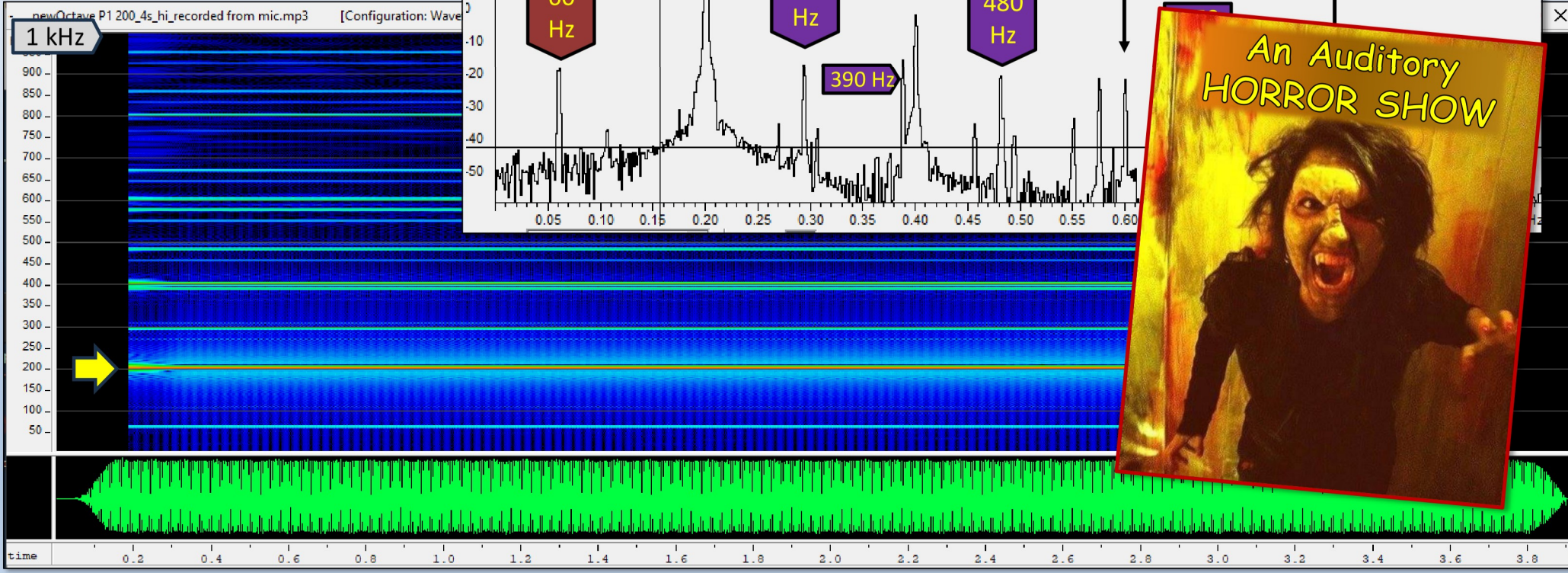




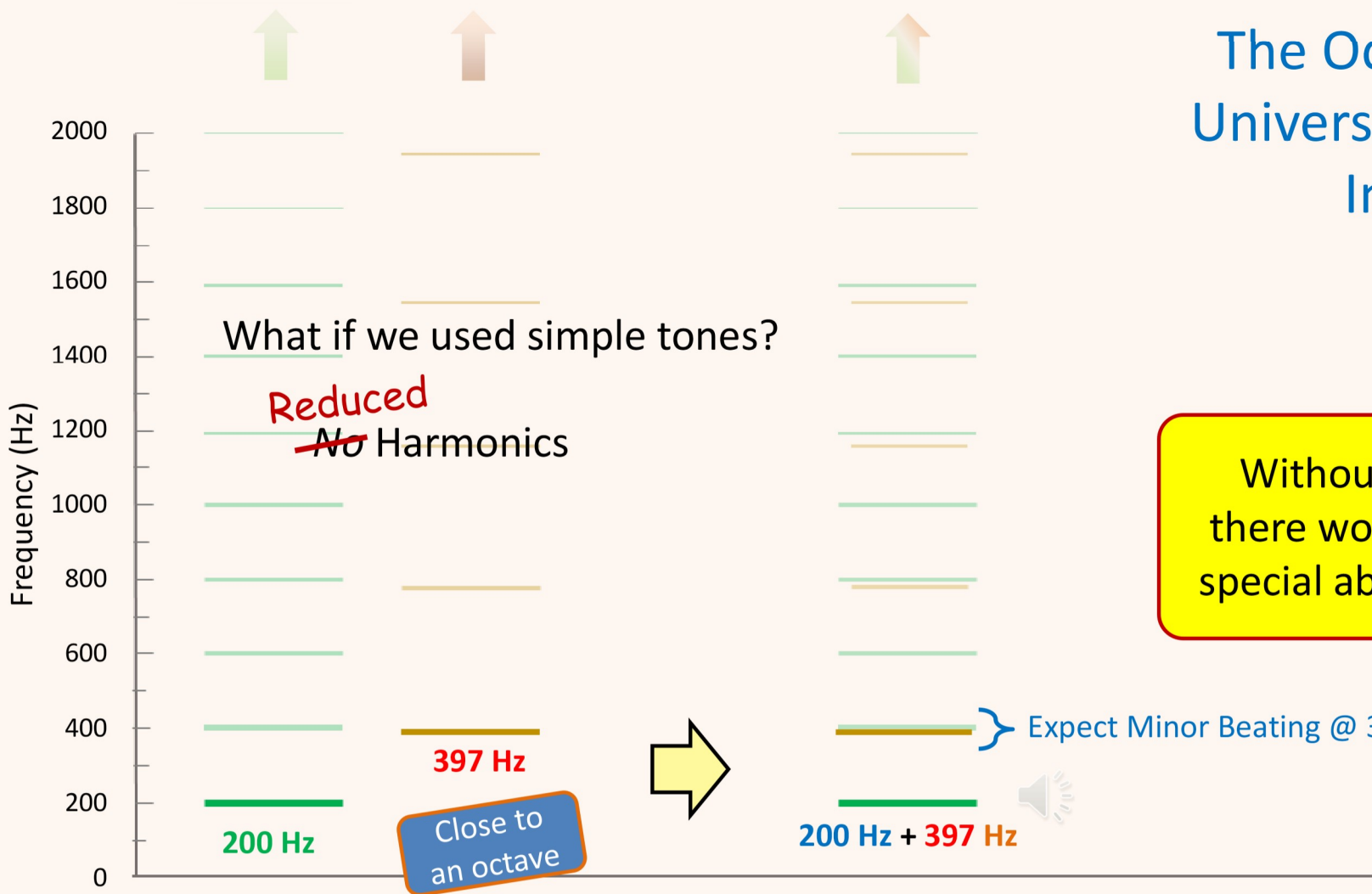
# 200 Hz Pure Tone as Heard Through Imperfect Loudspeakers!



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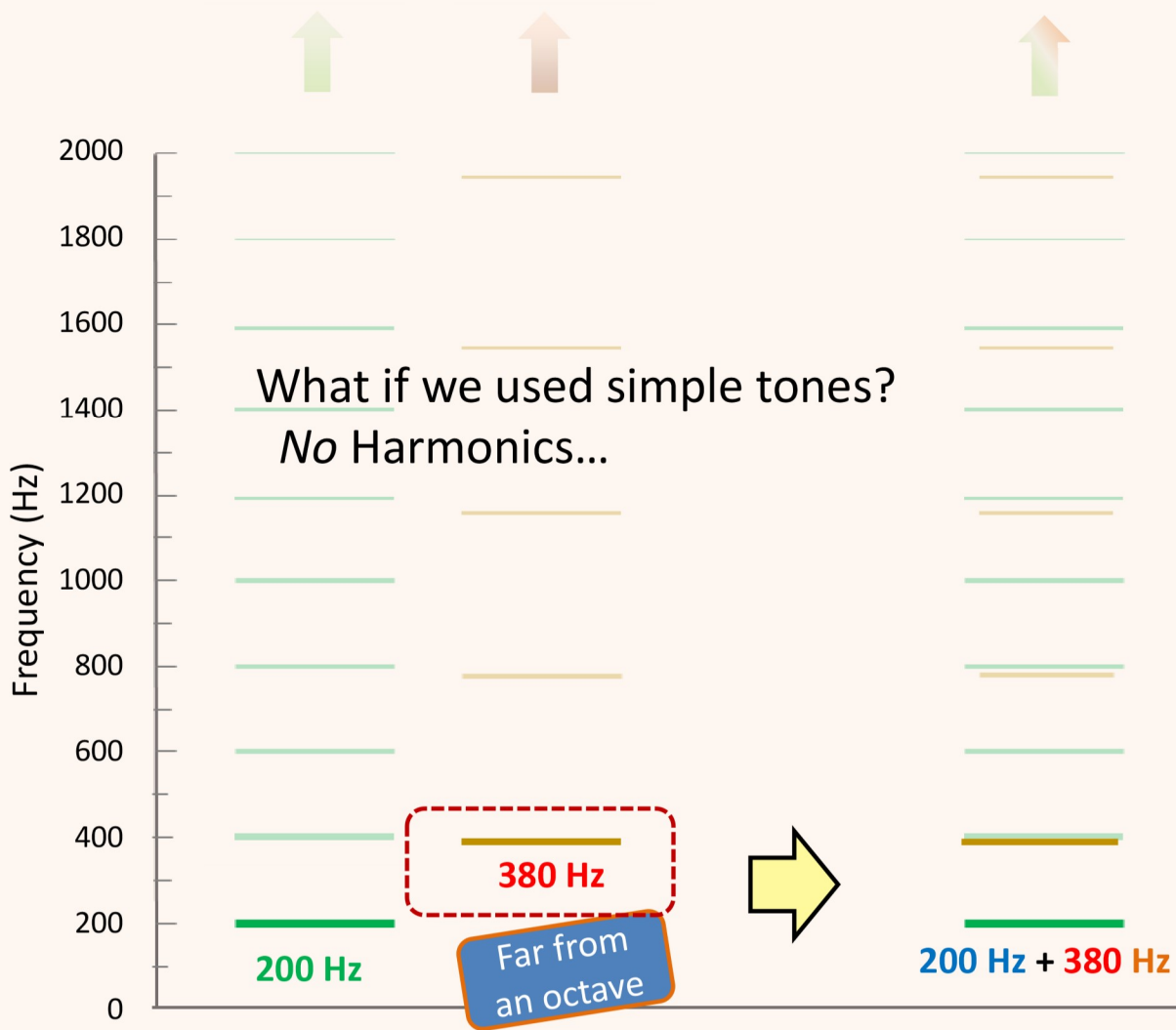
# The Octave As the Universal Frequency Interval $2x$



Without Harmonics, there would be nothing special about the Octave



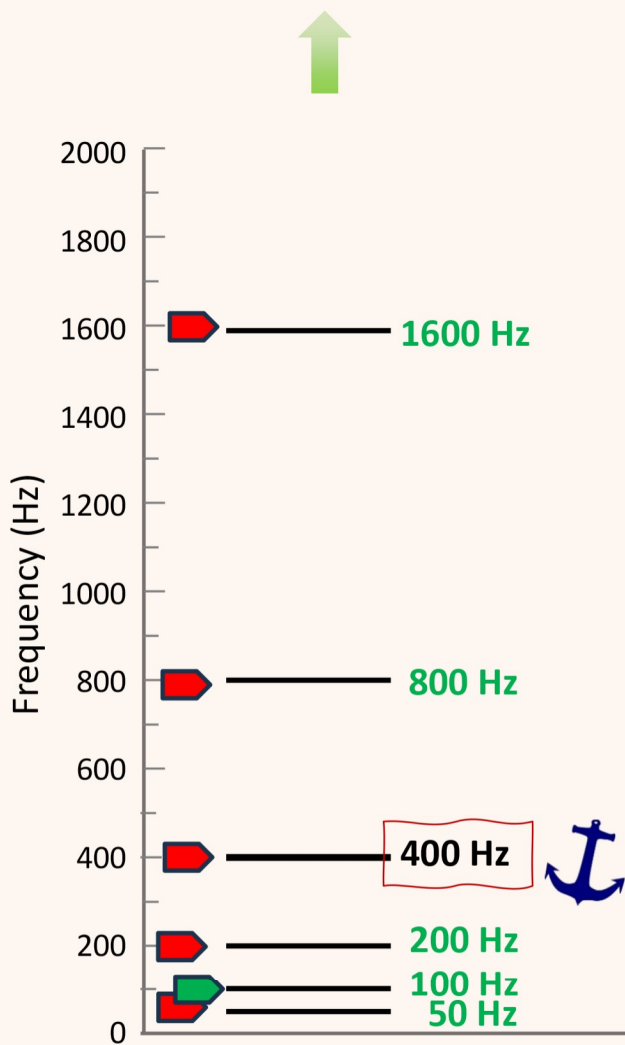
# The Octave As the Universal Frequency Interval $2x$



- Without Harmonics, Nothing Special about the octave



# The Octave As the Universal Frequency Interval $2x$



So what does our Skeleton Scale Sound like?

- With real musical notes having harmonics, Octave Ratios are a very good thing
  - *most musical instruments are rich in harmonics*
- Virtually all formal musical traditions organize scales by Octaves
- We will therefore construct Scales based on Octave Ratios

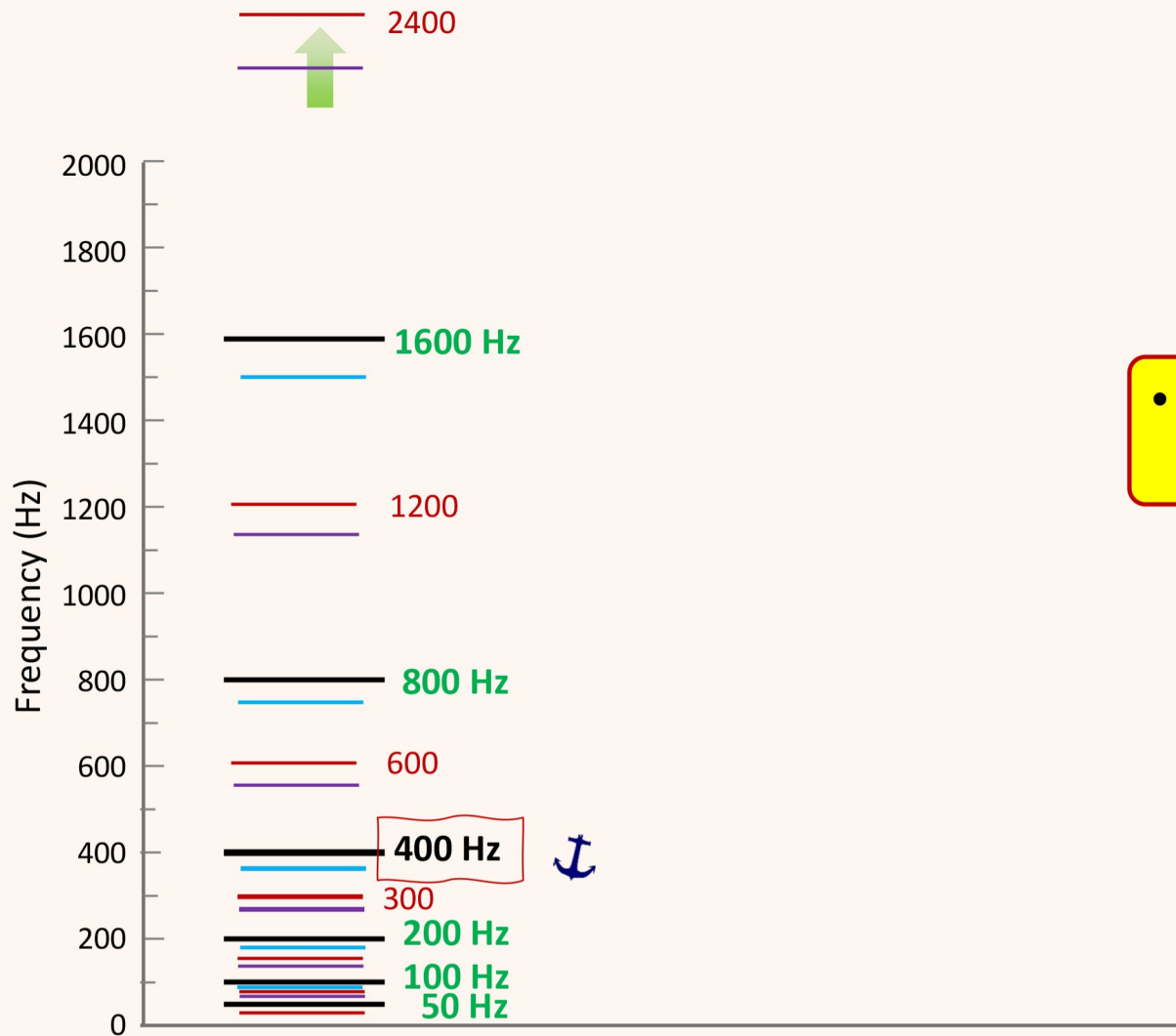


"Intervals"  
in Musical Lingo

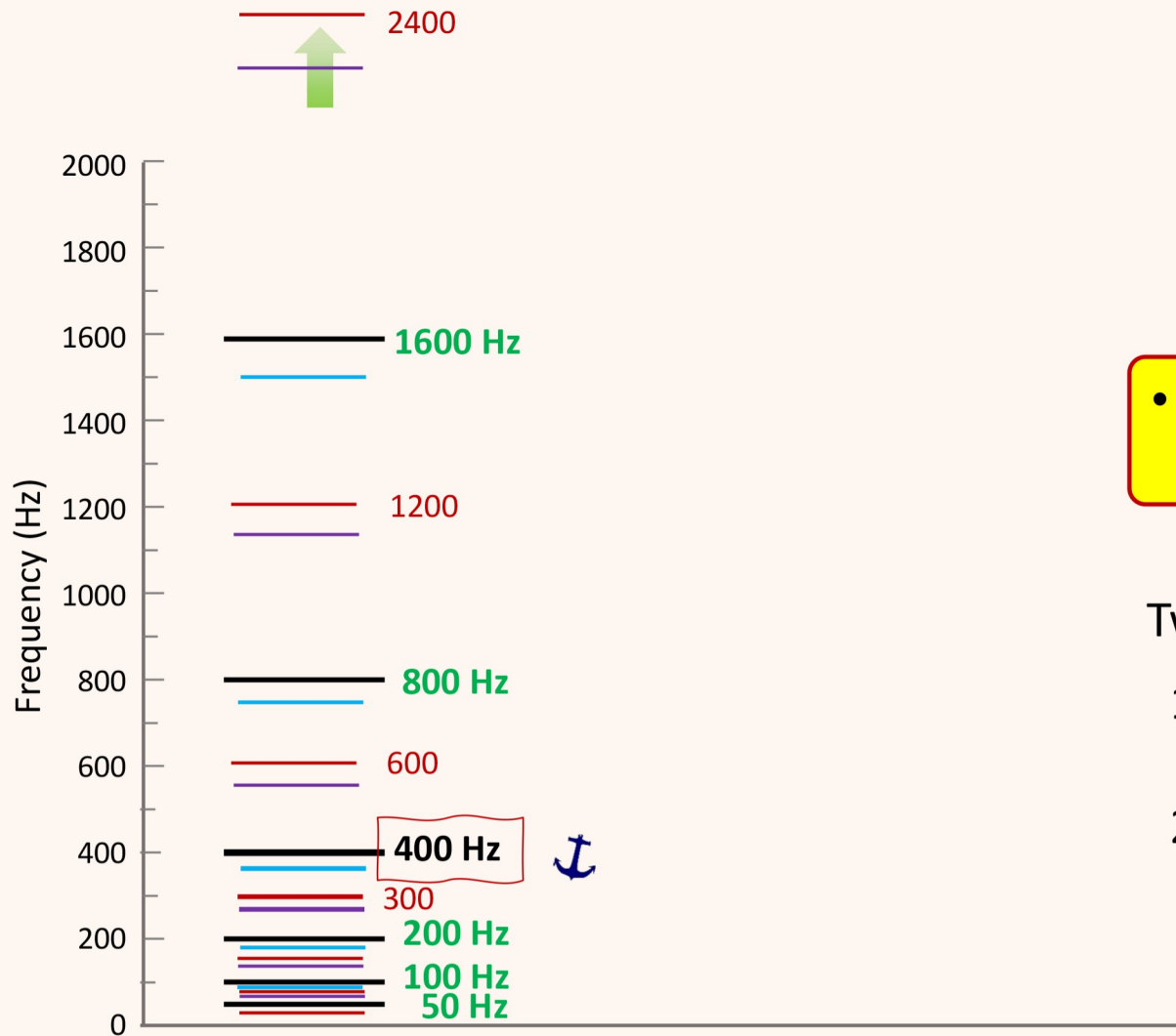


# Constructing Scales based on Octaves

- If we add a note in one Octave, we need to add it in *all* Octaves.



# Constructing Scales based on Octaves



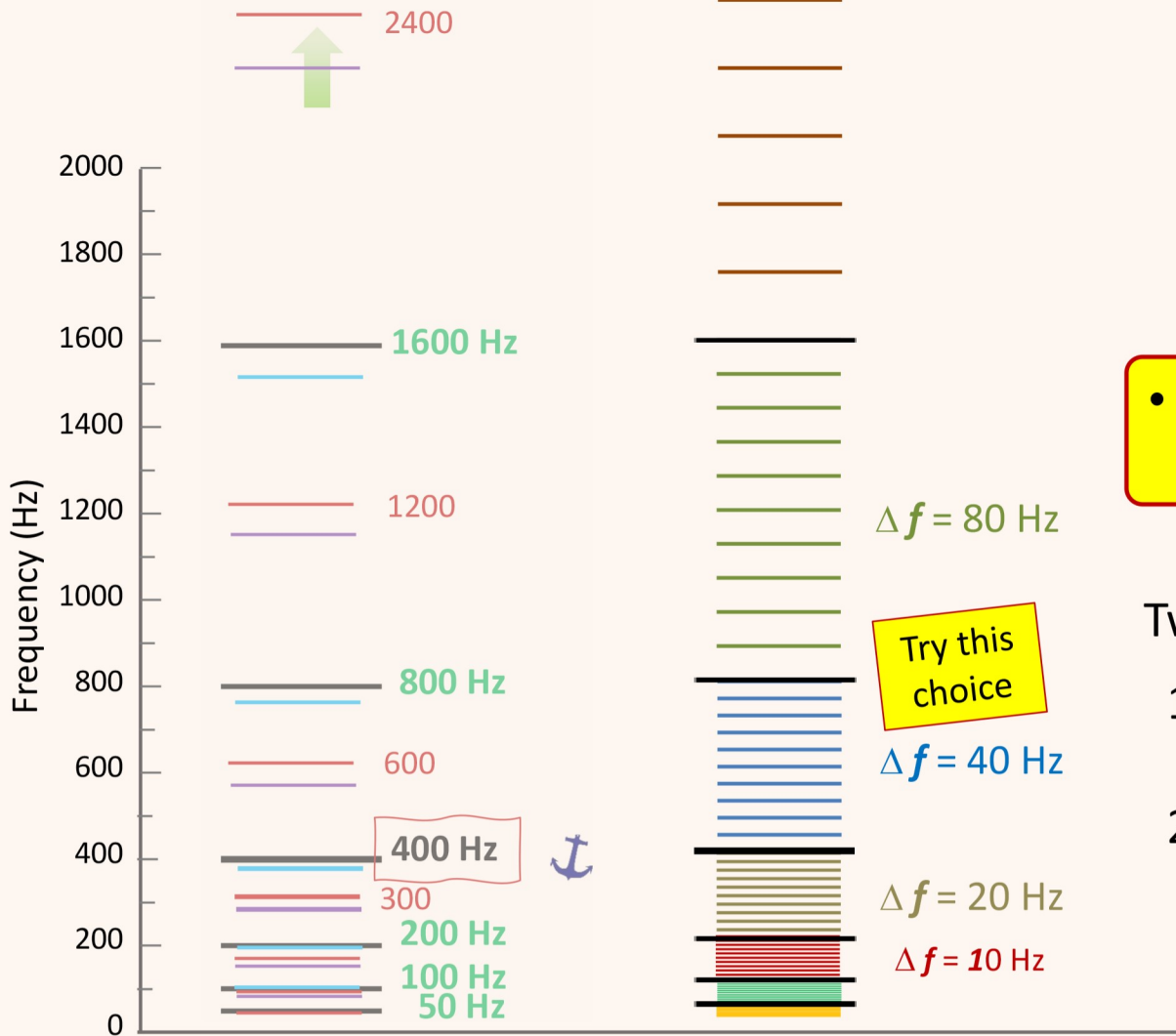
- If we add a note in one Octave, we need to add it in *all* Octaves.

Two Choices to Make:

1. How many notes per Octave?
2. How should they be distributed?  
- i.e., exactly what frequencies?

TEMPERAMENT

# Constructing Scales based on Octaves



• If we add a note in one Octave, we need to add it in *all* Octaves.

Two Choices to Make:

1. How many notes per Octave?
2. How should they be distributed?  
- i.e., exactly what frequencies?

TEMPERAMENT



A monk\* came up with an answer 1000 years ago...

## Old MacDonald Had A Farm

*Anonymous*  
*Arr: Raif Husicic*

$\text{♩} = 110$



Log of  
Frequency

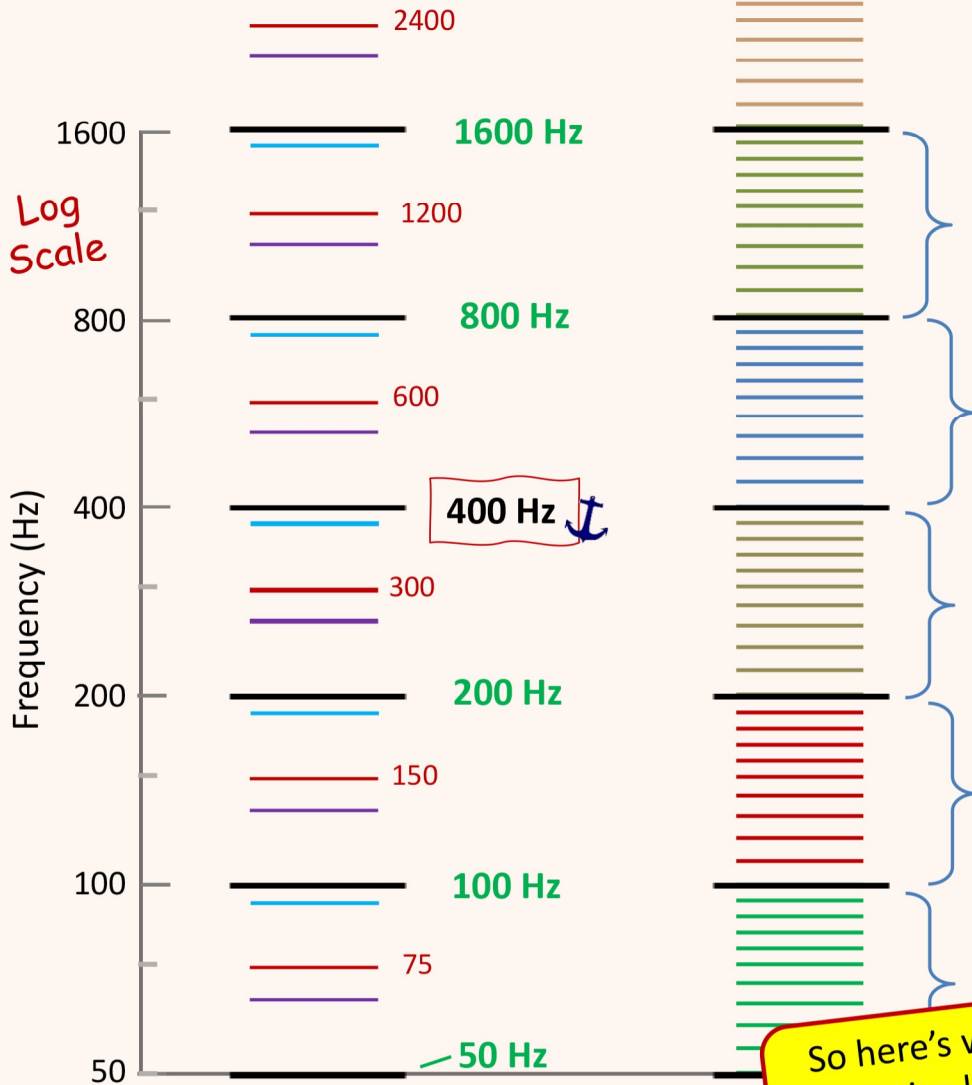
(Approximately)

\*Guido of Arezzo 1025





# Constructing Scales based on Octaves



• If we add a note in one Octave, we need to add it in *all* Octaves.

Two Choices to Make:

1. How many notes per Octave?
2. How should they be distributed?  
- i.e., exactly what frequencies?

So here's what the previous choice looks like with a Logarithmic Frequency Scale

TEMPERAMENT

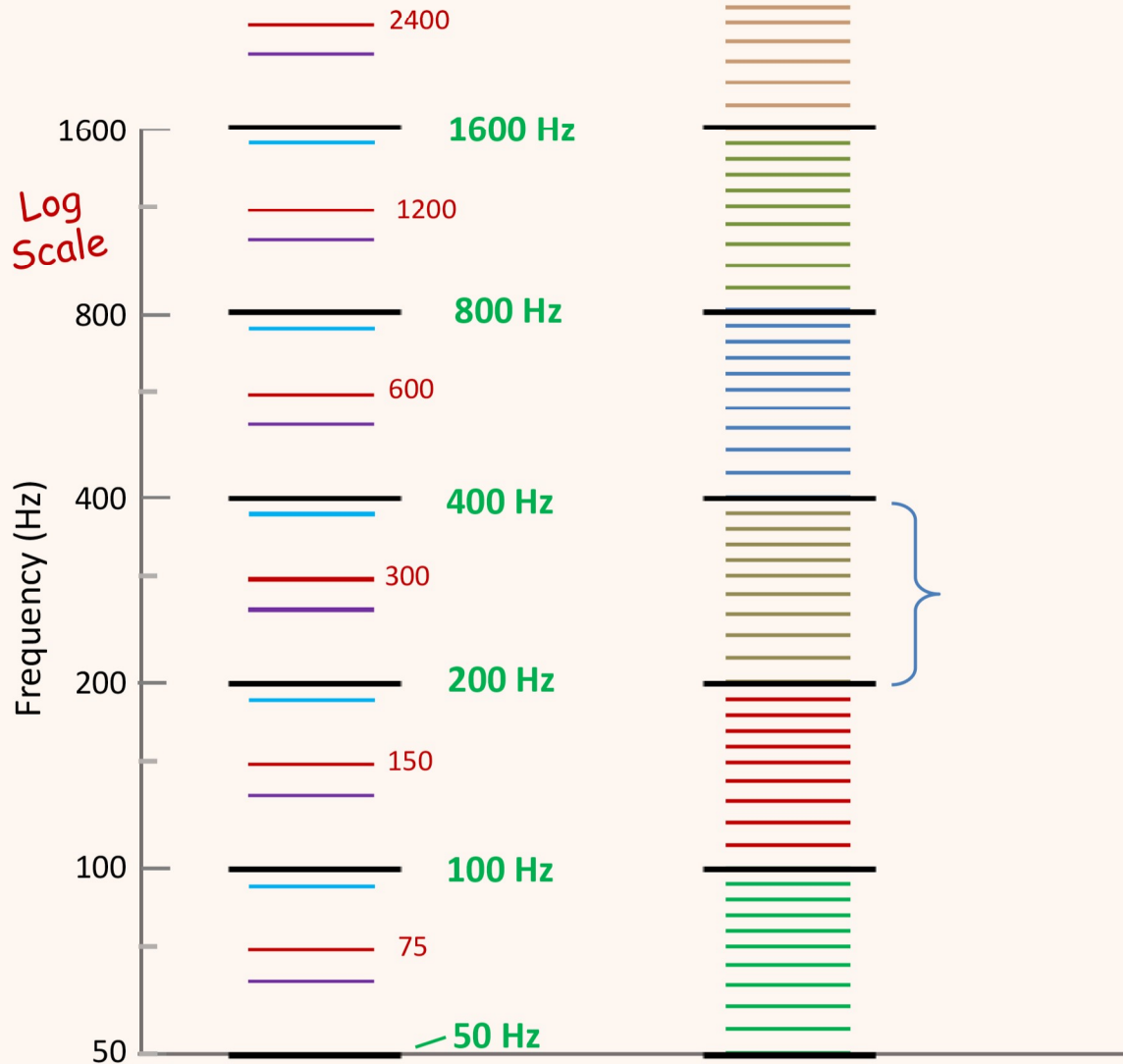


# Constructing Scales based on Octaves

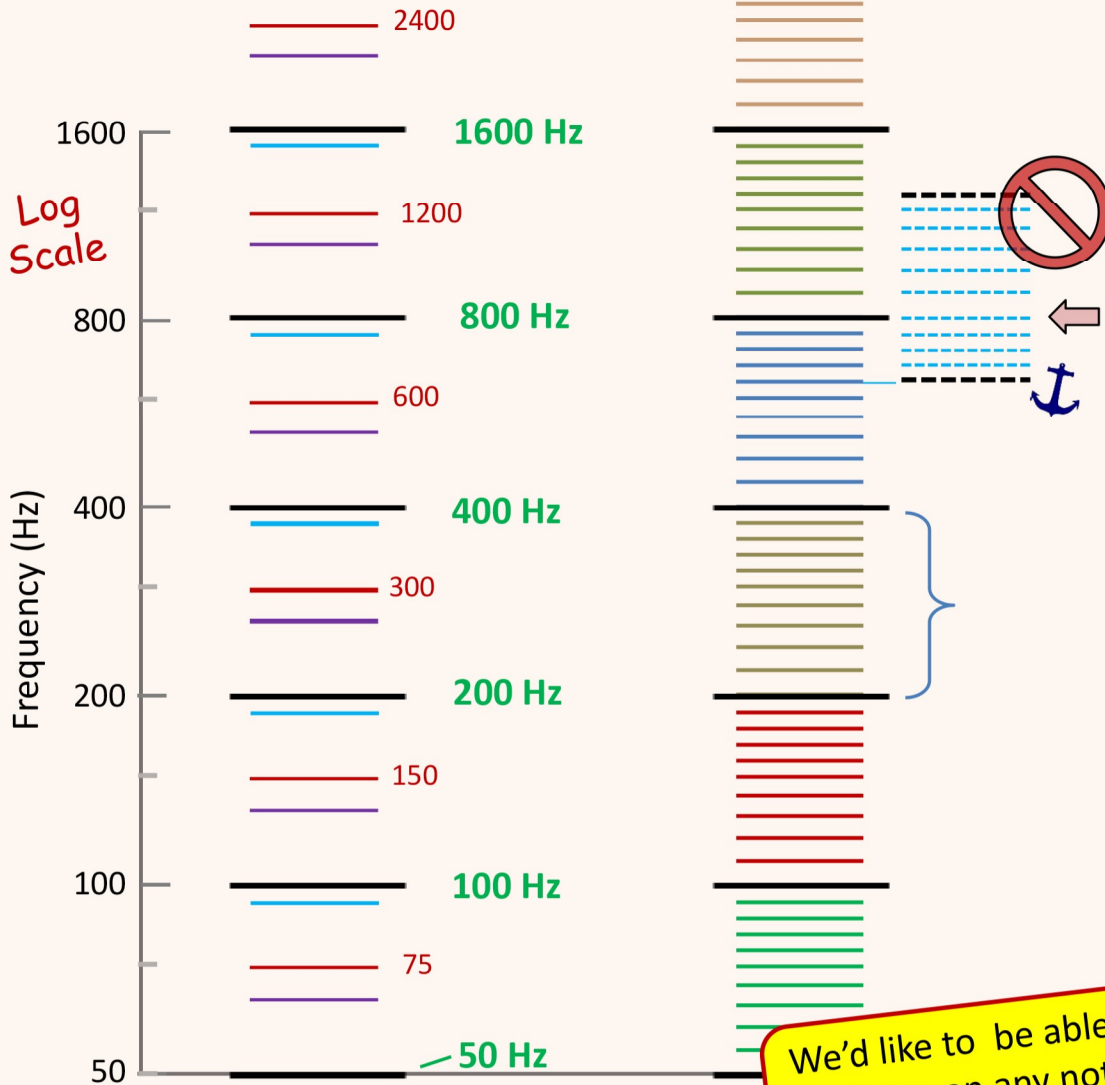
## Two Choices to Make:

1. How many notes per Octave?

- *Enough* to make interesting music but...
- Not *too* many, lest we
  - Over-complicate Instruments
  - Confuse listeners
  - Burden Composers
- **Actual scales use from 5 to 24 notes/octave**



# Constructing Scales based on Octaves



## Two Choices to Make:

1. How many notes per Octave?
  2. How should they be distributed?  
- i.e., exactly what frequencies?
- We want to choose notes that play well together for melody and harmony
  - Ideally, we'd like a smooth, regular distribution
    - Better yet, so regular that we could anchor our octaves on any note and get the same pattern!

We'd like to be able to anchor our octaves on any note and get the same pattern

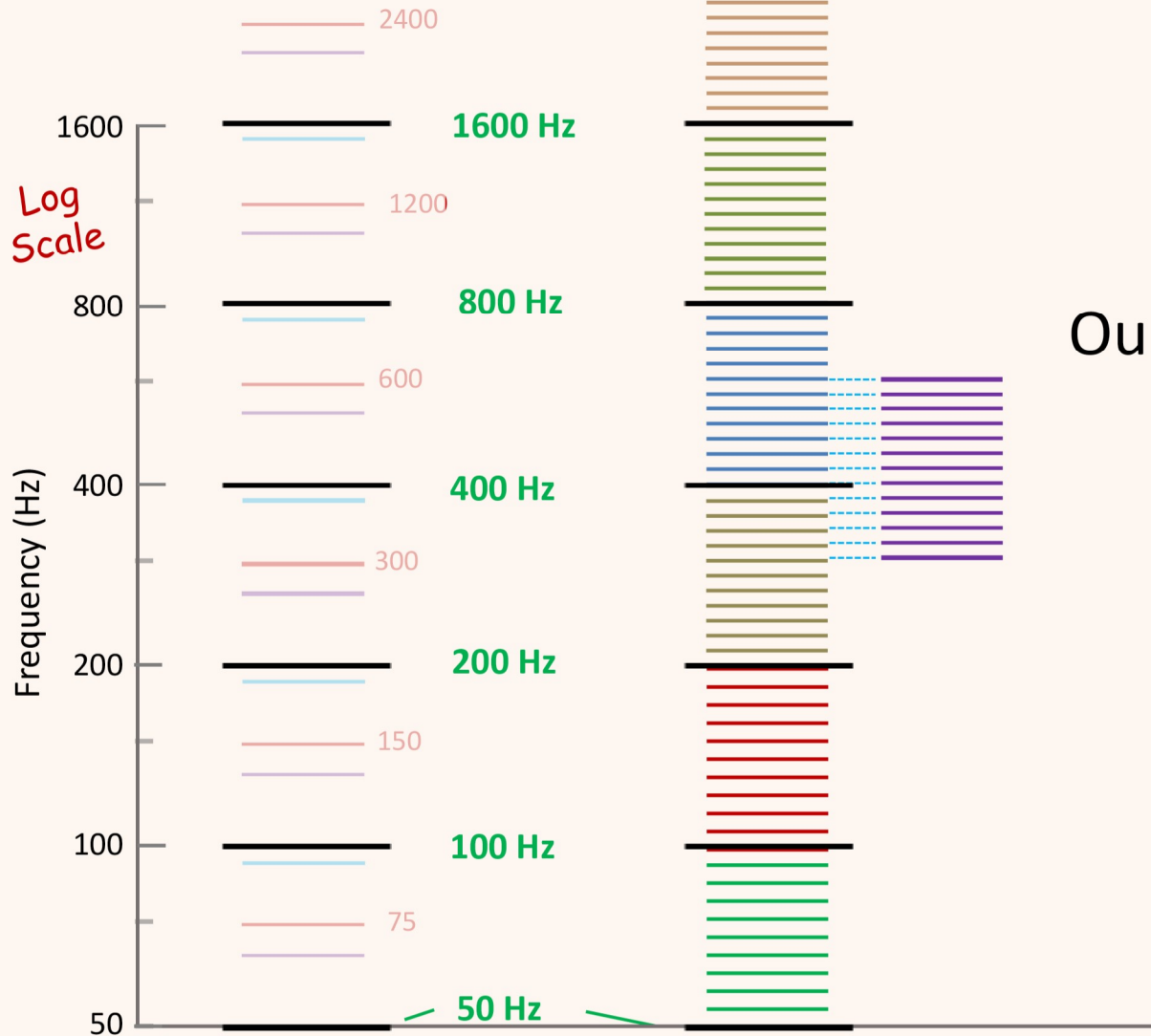
# Constructing Scales based on Octaves

Our Focus: ~~“Mother Scale”~~ ?  
*Great-great Granddaughter*

- 12 Notes Per Octave
- Equal Spacing (on Log Scale)

- Clean
- Simple
- Elegant

... but not musically ideal 😞





# So What Is This Mother Scale?

Log Scale

Frequency  $f \rightarrow$



Octave

12	200 Hz
11	188.8
10	178.2
9	168.2
8	158.7
7	149.8
6	141.42136
5	133.5
4	126.0
3	118.9
2	112.2
1	105.9 Hz
0	100 Hz

- 12 Notes Per Octave
- Equal Spacing (on Log Scale)
  - Equal Ratios of Adjacent Frequencies
    - Ratio =  $1.05946\dots$
    - Each note  $\approx$  6% Higher

$$12\sqrt[12]{2}$$

6% increase

Compound Interest:  
At 5.9% you will  
Double Your Money  
in 12 years



# So What Is This Mother Scale?

Log Scale

Frequency  $f \rightarrow$



$$12\sqrt[12]{2}$$

Notes Per Octave

Spacing (on Log Scale)

Equal Ratios of Adjacent Frequencies

Ratio = **1.05946...**

Each note  $\approx$  6% Higher

Compound Interest:  
At 5.9% you will  
Double Your Money  
in 12 years

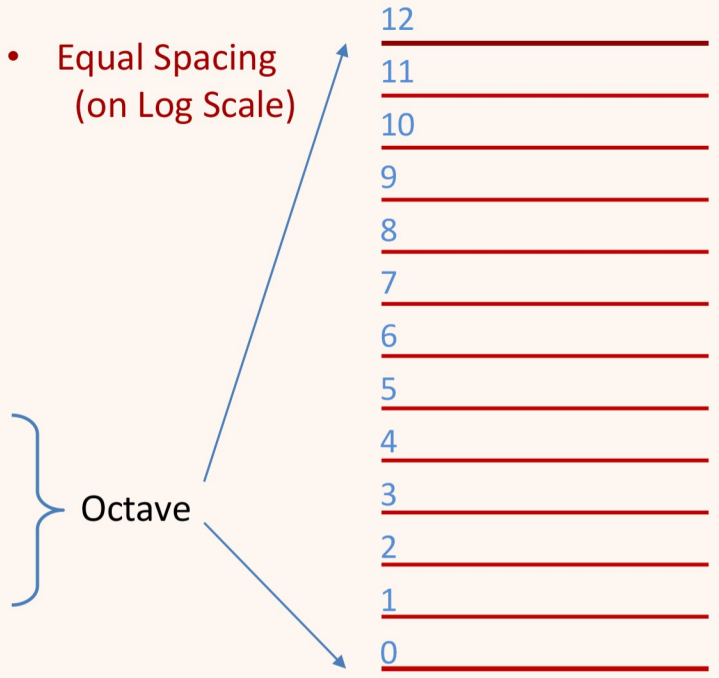


# So What Is This Mother Scale?

Log Scale

Frequency  $f \rightarrow$

- 12 Notes Per Octave
- Equal Spacing (on Log Scale)

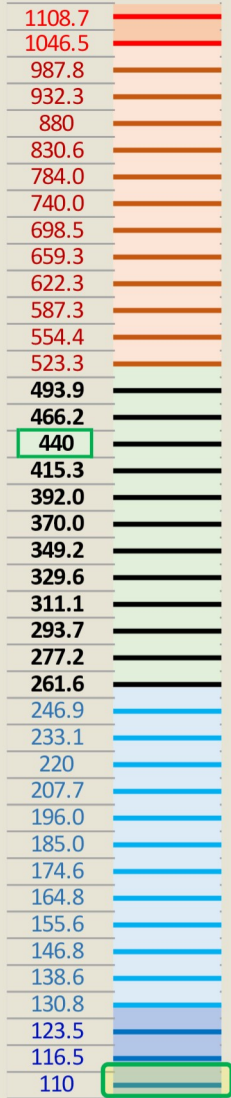


~~100 Hz~~  
130.81 Hz

A Particular Example of such a 12-tone Equal Tempered scale is...  
...  
“The 12 Tone Chromatic Scale”



*f*



Simple Tones

Complex Tones

# 12 Note Per Octave Equal Tempered Scale: The Chromatic Scale

Here's what the scale sounds like..





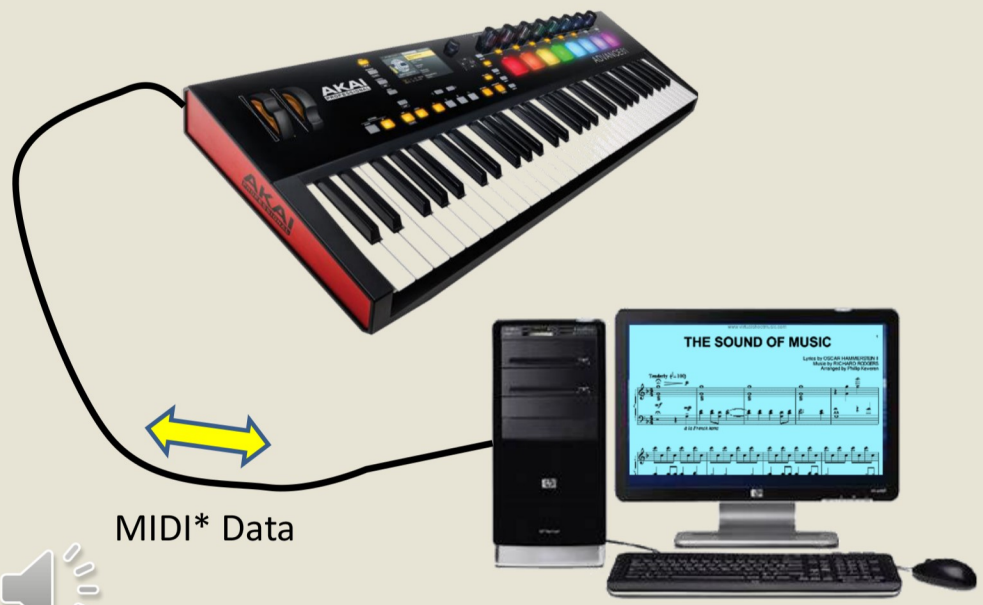
# 12 Note Per Octave Equal Tempered Scale: The Chromatic Scale

Piano **MIDI** *f*

Frequency (Hz)	MIDI Note	Frequency (Hz)
65	85	1108.7
64	84	1046.5
63	83	987.8
62	82	932.3
61	81	880
60	80	830.6
59	79	784.0
58	78	740.0
57	77	698.5
56	76	659.3
55	75	622.3
54	74	587.3
53	73	554.4
52	72	523.3
51	71	493.9
50	70	466.2
49	69	440
48	68	415.3
47	67	392.0
46	66	370.0
45	65	349.2
44	64	329.6
43	63	311.1
42	62	293.7
41	61	277.2
40	60	261.6
39	59	246.9
38	58	233.1
37	57	220
36	56	207.7
35	55	196.0
34	54	185.0
33	53	174.6
32	52	164.8
31	51	155.6
30	50	146.8
29	49	138.6
28	48	130.8
27	47	123.5
26	46	116.5
25	45	110

Simple Tones

Complex Tones



MIDI\* Data

\* Musical Instrument Digital Interface

# 12 Note Per Octave Equal Tempered Scale: The Chromatic Scale

MIDI	<i>f</i>		Solfège	Pitch Class
85	1108.7		C#/D♭ 6	
84	1046.5		C 6	0
83	987.8		B 5	11
82	932.3		A#/B♭ 5	
81	880		A 5	
80	830.6		G#/A♭ 5	
79	784.0		G 5	
78	740.0		F#/G♭ 5	
77	698.5		F 5	
76	659.3		E 5	
75	622.3		D#/E♭ 5	
74	587.3		D 5	
73	554.4		C#/D♭ 5	
72	523.3		C 5	0
71	493.9		B 4	
70	466.2		A#/B♭ 4	
69	440		A 4	
68	415.3		G#/A♭ 4	
67	392.0		G 4	
66	370.0		F#/G♭ 4	
65	349.2		F 4	
64	329.6		E 4	
63	311.1		D#/E♭ 4	
62	293.7		D 4	
61	277.2		C#/D♭ 4	
60	261.6		C 4	0
59	246.9		B 3	
58	233.1		A#/B♭ 3	
57	220		A 3	
56	207.7		G#/A♭ 3	
55	196.0		G 3	
54	185.0		F#/G♭ 3	
53	174.6		F 3	
52	164.8		E 3	
51	155.6		D#/E♭ 3	
50	146.8		D 3	
49	138.6		C#/D♭ 3	
48	130.8		C 3	0
47	123.5		B 2	
46	116.5		A#/B♭ 2	
45	110		A 2	

All the C notes  
belong to  
Pitch Class Zero



# 12 Note Per Octave Equal Tempered Scale: The Chromatic Scale

MIDI	<i>f</i>		Pitch Class
85	1108.7		C#/D♭ 6
84	1046.5		C 6
83	987.8		B 5
82	932.3		A#/B♭ 5
81	880		A 5
80	830.6		G#/A♭ 5
79	784.0		G 5
78	740.0		F#/G♭ 5
77	698.5		F 5
76	659.3		E 5
75	622.3		D#/E♭ 5
74	587.3		D 5
73	554.4		C#/D♭ 5
72	523.3		C 5
71	493.9		B 4
70	466.2		A#/B♭ 4
69	440		A 4
68	415.3		G#/A♭ 4
67	392.0		G 4
66	370.0		F#/G♭ 4
65	349.2		F 4
64	329.6		E 4
63	311.1		D#/E♭ 4
62	293.7		D 4
61	277.2		C#/D♭ 4
60	261.6		C 4
59	246.9		B 3
58	233.1		A#/B♭ 3
57	220		A 3
56	207.7		G#/A♭ 3
55	196.0		G 3
54	185.0		F#/G♭ 3
53	174.6		F 3
52	164.8		E 3
51	155.6		D#/E♭ 3
50	146.8		D 3
49	138.6		C#/D♭ 3
48	130.8		C 3
47	123.5		B 2
46	116.5		A#/B♭ 2
45	110		A 2

All the C notes  
belong to  
Pitch Class Zero

# 12 Note Per Octave Equal Tempered Scale: The Chromatic Scale

MIDI	<i>f</i>		Pitch Class	Solfège
85	1108.7		C#/D♭ 6	Di
84	1046.5		C 6	0 Do
83	987.8		B 5	11 Ti
82	932.3		A#/B♭ 5	10 Li
81	880		A 5	9 La
80	830.6		G#/A♭ 5	8 Si
79	784.0		G 5	7 Sol
78	740.0		F#/G♭ 5	6 Fi
77	698.5		F 5	5 Fa
76	659.3		E 5	4 Mi
75	622.3		D#/E♭ 5	3 Ri
74	587.3		D 5	2 Re
73	554.4		C#/D♭ 5	1 Di
72	523.3		C 5	0 Do
71	493.9		B 4	11 Ti
70	466.2		A#/B♭ 4	10 Li
69	440		A 4	9 La
68	415.3		G#/A♭ 4	8 Si
67	392.0		G 4	7 Sol
66	370.0		F#/G♭ 4	6 Fi
65	349.2		F 4	5 Fa
64	329.6		E 4	4 Mi
63	311.1		D#/E♭ 4	3 Ri
62	293.7		D 4	2 Re
61	277.2		C#/D♭ 4	1 Di
60	261.6		C 4	0 Do
59	246.9		B 3	11 Ti
58	233.1		A#/B♭ 3	10 Li
57	220		A 3	9 La
56	207.7		G#/A♭ 3	8 Si
55	196.0		G 3	7 Sol
54	185.0		F#/G♭ 3	6 Fi
53	174.6		F 3	5 Fa
52	164.8		E 3	4 Mi
51	155.6		D#/E♭ 3	3 Ri
50	146.8		D 3	2 Re
49	138.6		C#/D♭ 3	1 Di
48	130.8		C 3	0 Do
47	123.5		B 2	Ti
46	116.5		A#/B♭ 2	Li
45	110		A 2	La





# 12 Note Per Octave Equal Tempered Scale: The Chromatic Scale

MIDI	<i>f</i>		Note	Pitch Class	Solfège
85	1108.7		C#/D $\flat$ 6	1	Di
84	1046.5		C 6	0	Do
83	987.8		B 5	11	Ti
82	932.3		A#/B $\flat$ 5	10	Li
81	880		A 5	9	La
80	830.6		G#/A $\flat$ 5	8	Si
79	784.0		G 5	7	Sol
78	740.0		F#/G $\flat$ 5	6	Fi
77	698.5		F 5	5	Fa
76	659.3		E 5	4	Mi
75	622.3		D#/E $\flat$ 5	3	Ri
74	587.3		D 5	2	Re
73	554.4		C#/D $\flat$ 5	1	Di
72	523.3		C 5	0	Do
71	493.9		B 4	11	Ti
70	466.2		A#/B $\flat$ 4	10	Li
69	440		A 4	9	La
68	415.3		G#/A $\flat$ 4	8	Si
67	392.0		G 4	7	Sol
66	370.0		F#/G $\flat$ 4	6	Fi
65	349.2		F 4	5	Fa
64	329.6		E 4	4	Mi
63	311.1		D#/E $\flat$ 4	3	Ri
62	293.7		D 4	2	Re
61	277.2		C#/D $\flat$ 4	1	Di
60	261.6		C 4	0	Do
59	246.9		B 3	11	Ti
58	233.1		A#/B $\flat$ 3	10	Li
57	220		A 3	9	La



# 12 Note Per Octave Equal Tempered Scale: The Chromatic Scale

MIDI	<i>f</i>	Note	Pitch Class	Solfège
85	1108.7	C#/D $\flat$ 6	1	Di
84	1046.5	C 6	0	Do
83	987.8	B 5	11	Ti
82	932.3	A#/B $\flat$ 5	10	Li
81	880	A 5	9	La
80	830.6	G#/A $\flat$ 5	8	Si
79	784.0	G 5	7	Sol
78	740.0	F#/G $\flat$ 5	6	Fi
77	698.5	F 5	5	Fa
76	659.3	E 5	4	Mi
75	622.3	D#/E $\flat$ 5	3	Ri
74	587.3	D 5	2	Re
73	554.4	C#/D $\flat$ 5	1	Di
72	523.3	C 5	0	Do
71	493.9	B 4	11	Ti
70	466.2	A#/B $\flat$ 4	10	Li
69	440	A 4	9	La
68	415.3	G#/A $\flat$ 4	8	Si
67	392.0	G 4	7	Sol
66	370.0	F#/G $\flat$ 4	6	Fi
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64	329.6	E 4	4	Mi
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62	293.7	D 4	2	Re
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60	261.6	C 4	0	Do
59	246.9	B 3	11	Ti

# 12 Note Per Octave Equal Tempered Scale: The Chromatic Scale



# Alternate Scales with $n \neq 12$ : “Microtonal Scales”



Easley Blackwood, Jr.  
(1933-2023)  
Former music professor at  
U. of Chicago

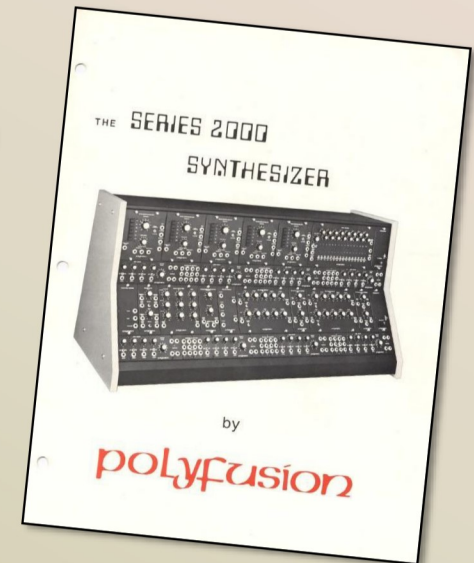
Example:

Fanfare in 19-note Equal Tuning, Op. 28a  
(Blackwood, Polyfusion Synthesizer)



Cedille Records 1994

Compositions in  
n-Tone Equal  
Temperament:  
13-tone  
To  
24-tone Scales  
(Synthesizer  
and  
Modified Guitar)





## Question Time

- Octaves
- Number of Notes per octave
  - Microtonal
- Temperament
- Solfege



- Zoomland
- In Person



# 12 Note Per Octave Equal Tempered Scale: The Chromatic Scale

MIDI	<i>f</i>		Note	Pitch Class	Solfège
85	1108.7		C#/D $\flat$ 6	1	Di
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83	987.8		B 5	11	Ti
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59	246.9		B 3	11	Ti



# Subscales of The Chromatic Scale

Note	MIDI	<i>f</i>	Chromatic Scale
C#/D $\flat$ 6	85	1108.7	
C 6	84	1046.5	
B 5	83	987.8	
A#/B $\flat$ 5	82	932.3	
A 5	81	880	
G#/A $\flat$ 5	80	830.6	
G 5	79	784.0	
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C 5	72	523.3	
B 4	71	493.9	
A#/B $\flat$ 4	70	466.2	
A 4	69	440	
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D 4	62	293.7	
C#/D $\flat$ 4	61	277.2	
C 4	60	261.6	
B 3	59	246.9	

- Most Western music genres do **not** use the whole Chromatic Scale
  - Instead, they use smaller Subscales
- Such Subscale music includes:
  - Almost all pre-1910 music
    - Traditional
    - Classical
    - Liturgical
  - Pop music
  - Rock
  - Country and Bluegrass
- Music using the Chromatic Scale includes:
  - Modern “atonal” music (post-1910)
  - Much Jazz

Warning:  
It's not quite as simple as this...

# Subscales of The Chromatic Scale

Note	MIDI	<i>f</i>	Chromatic Scale
C#/D $\flat$ 6	85	1108.7	
C 6	84	1046.5	
B 5	83	987.8	
A#/B $\flat$ 5	82	932.3	
A 5	81	880	
G#/A $\flat$ 5	80	830.6	
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How many subscales are there?

Examples for  $m = 3$ -note Subscales

All together, **55** Patterns like these for  $m=3$

But each Pattern could be anchored at **12** different notes within an Octave

So there are  $12 \times 55 = \mathbf{660}$   $m=3$  Subscales



# Subscales of The Chromatic Scale

Note	MIDI	<i>f</i>	Chromatic Scale
C#/D $\flat$ 6	85	1108.7	
C 6	84	1046.5	
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C 4	60	261.6	
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m Notes	Patterns	Keys	Total Scales
1	1	12	12
2	11	12	132
3	55	12	660
4	165	12	1980
5	330	12	3960
6	462	12	5544
7	462	12	5544
8	330	12	3960
9	165	12	1980
10	55	12	660
11	11	12	132
12	1	12	12

# Subscales of The Chromatic Scale

Note	MIDI	<i>f</i>	Chromatic Scale
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C 6	84	1046.5	
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Traditional, Country Music, Blues

Classical, Pop, Rock

Heptatonic  
(Includes Diatonic)

Used for Jazz?

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2	11	12	132
3	55	12	660
4	165	12	1980
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10	55	12	660
11	11	12	132
12	1	12	12

Only a tiny fraction are useful!

# The Pentatonic (5 note) Subscales of The Chromatic Scale

There are **330**  $m=5$  Patterns...

But most are dumb like this

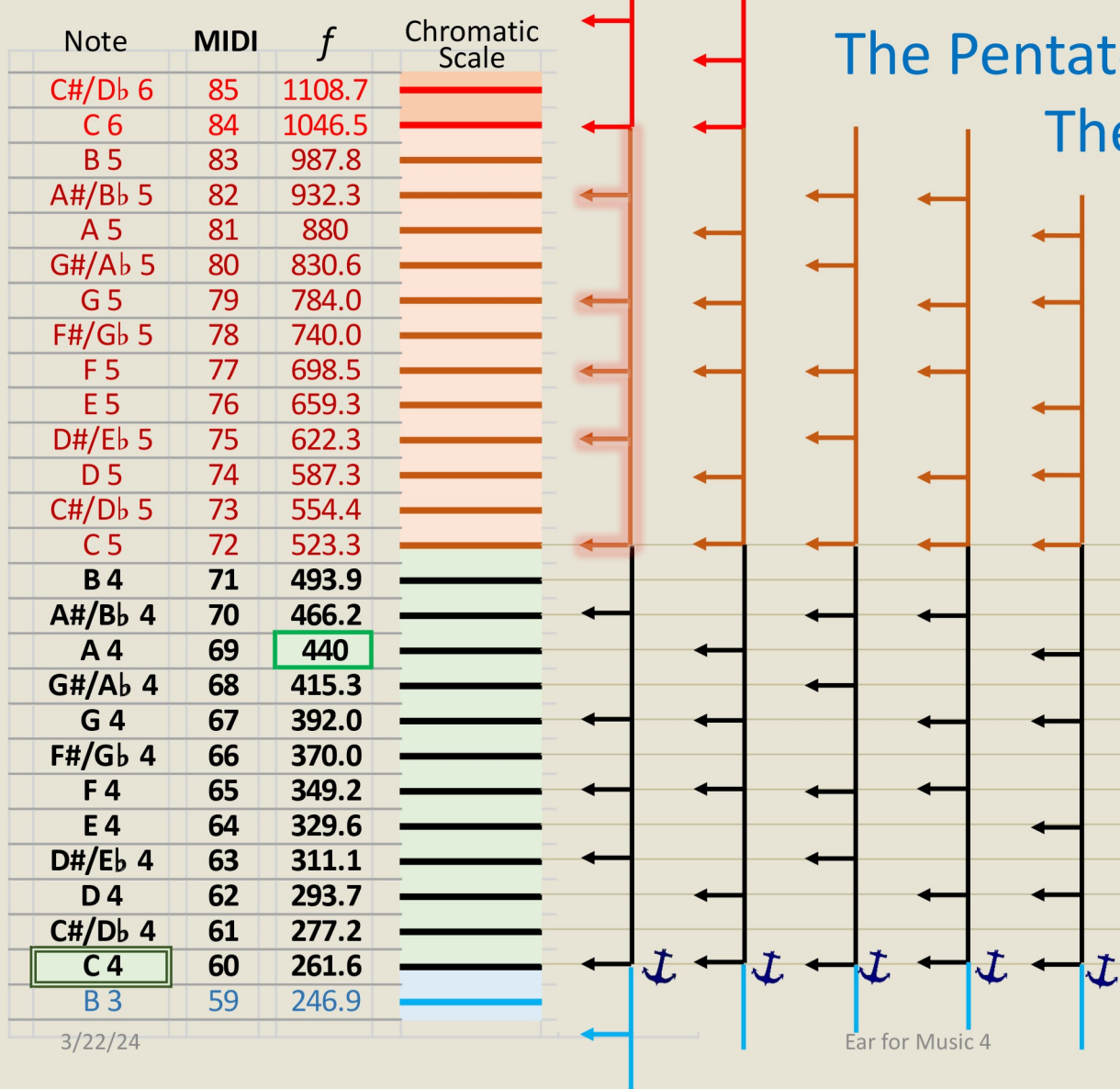
Reasonable rules:

1. Avoid gap of 4 or more
2. Avoid adjacent gaps of 3

With these rules, there are **just 5 Patterns possible!**

Note	MIDI	$f$	Chromatic Scale
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C 6	84	1046.5	
B 5	83	987.8	
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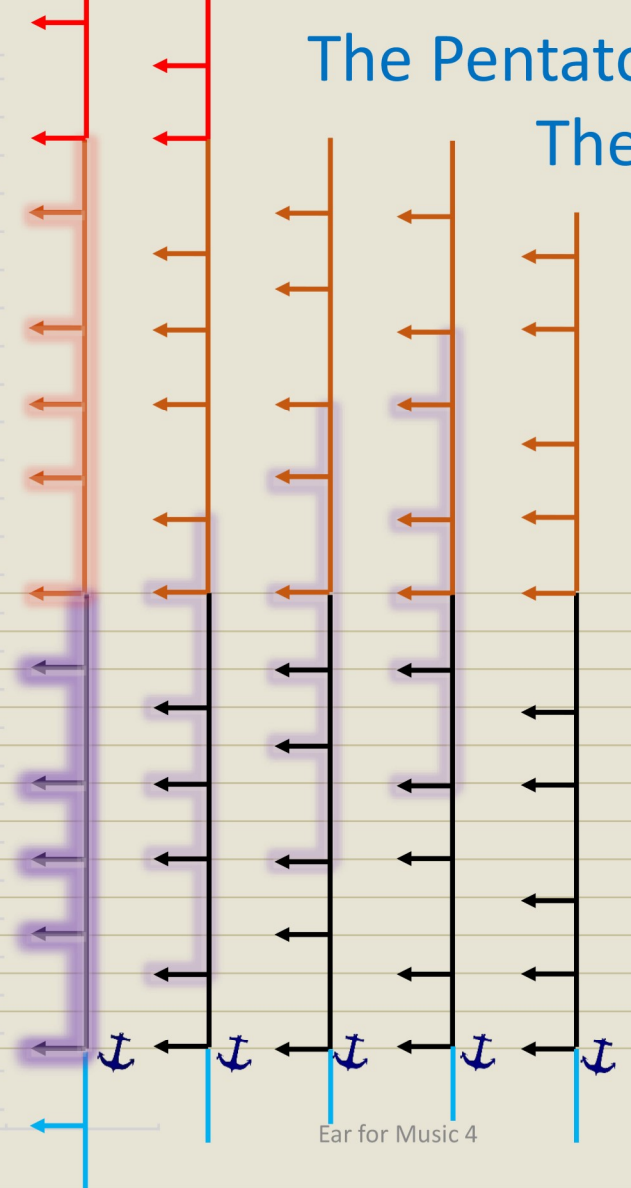
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# The Pentatonic (5 note) Subscales of The Chromatic Scale

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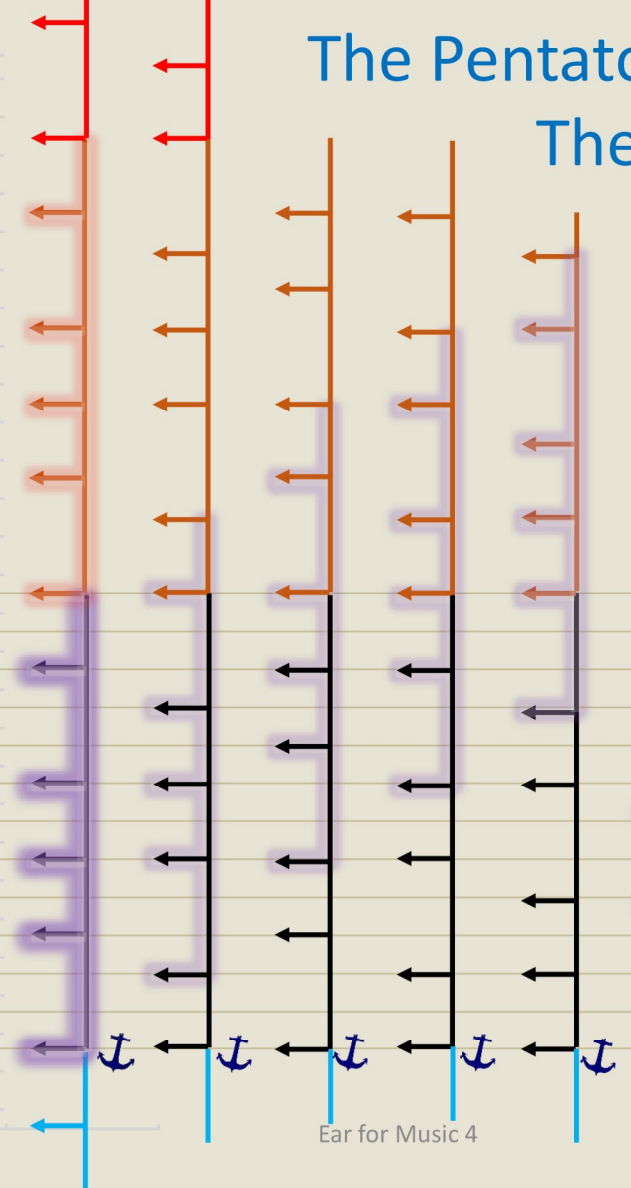
1. Avoid gap of 4 or more
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**With these rules, there are just 5 Patterns possible!**

But they're all really the same pattern, just shifted

# The Pentatonic (5 note) Subscales of The Chromatic Scale

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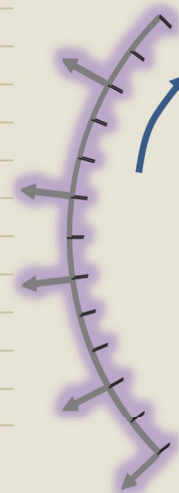


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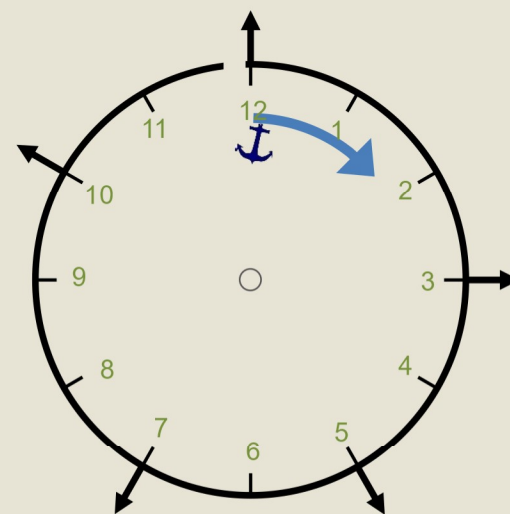
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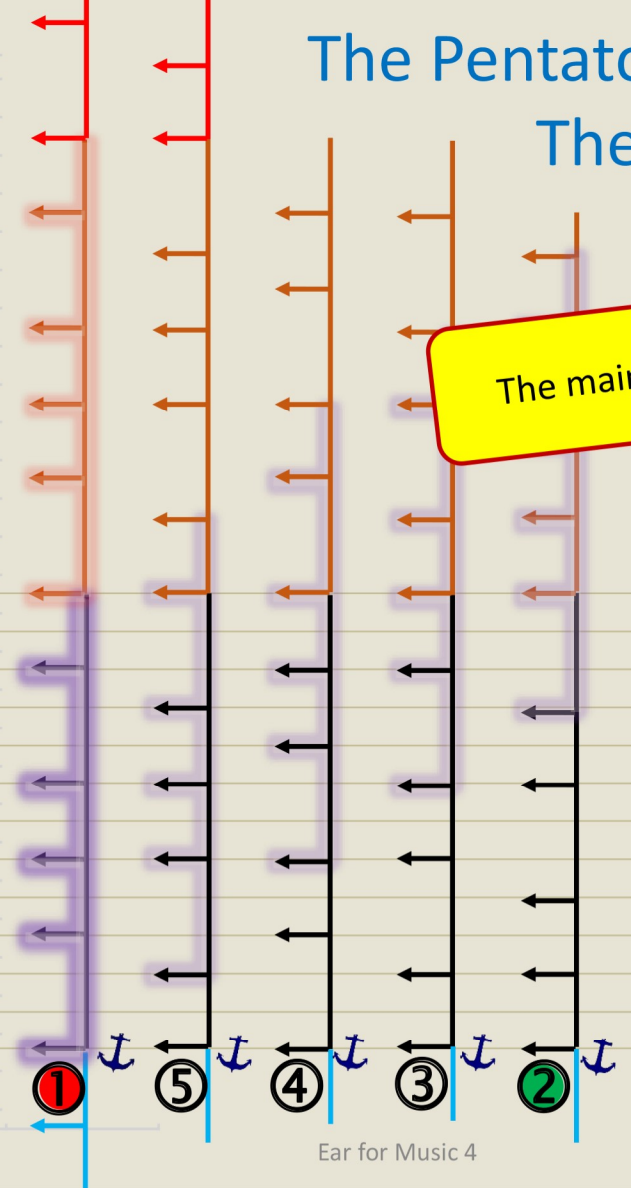






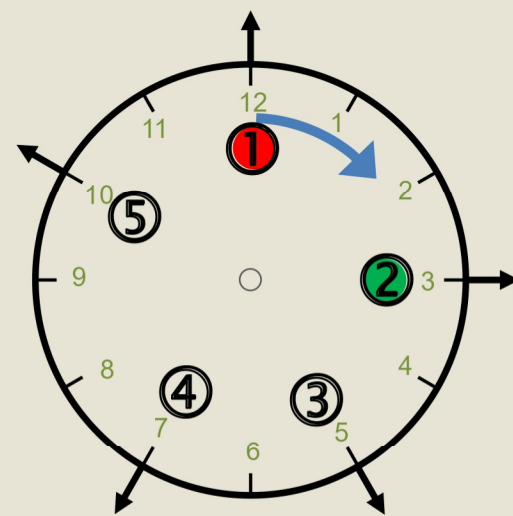
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The Pentatonic Scale Circle:  
Modes of the Pentatonic Scales

- ① minor Pentatonic Scale
- ② Major Pentatonic Scale



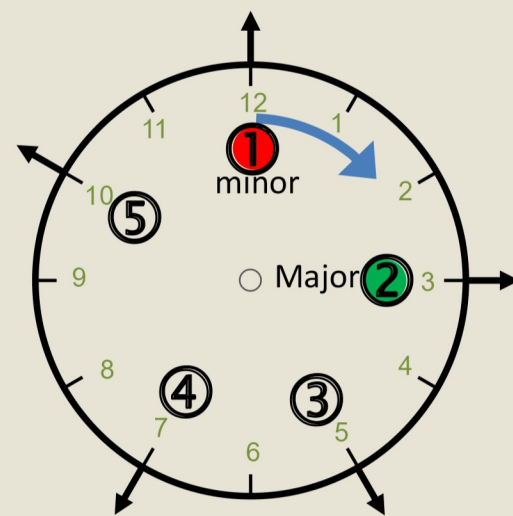


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The Pentatonic Scale Circle:  
5 Modes of the Pentatonic Scales

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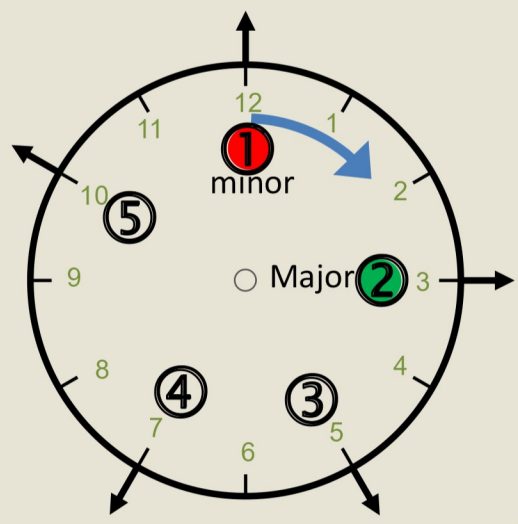
How can musicians remember these scales?

3-2-2-3-2

2-2-3-2-3 DDTDT

The Pentatonic Scale Circle:  
5 Modes of the Pentatonic Scales

- ① minor Pentatonic Scale
- ② Major Pentatonic Scale



# The Pentatonic (5 note) Subscales of The Chromatic Scale: 12 Keys

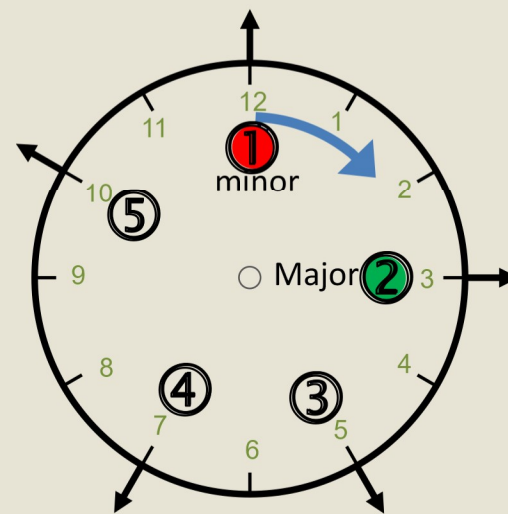
Note	MIDI	<i>f</i>	Chromatic Scale
C#/D $\flat$ 6	85	1108.7	
C 6	84	1046.5	
B 5	77	658.5	
E 5	76	659.3	
D#/E $\flat$ 5	75	622.3	
D 5	74	587.3	
C#/D $\flat$ 5	73	554.4	
C 5	72	523.3	
B 4	71	493.9	
A#/B $\flat$ 4	70	466.2	
A 4	69	440	
G#/A $\flat$ 4	68	415.3	
G 4	67	391.9	
F#/G $\flat$ 4	66	370.0	
F 4	65	349.2	
E 4	64	329.6	
D#/E $\flat$ 4	63	311.2	
D 4	62	293.7	
C#/D $\flat$ 4	61	277.2	
C 4	60	261.6	
B 3	59	246.9	

The Pentatonic Major Scale in 12 Keys →

Pentatonic Scale in Key of C Major

Curiosity: C Major Uses only White Piano Keys

- ① minor Pentatonic Scale
- ② Major Pentatonic Scale





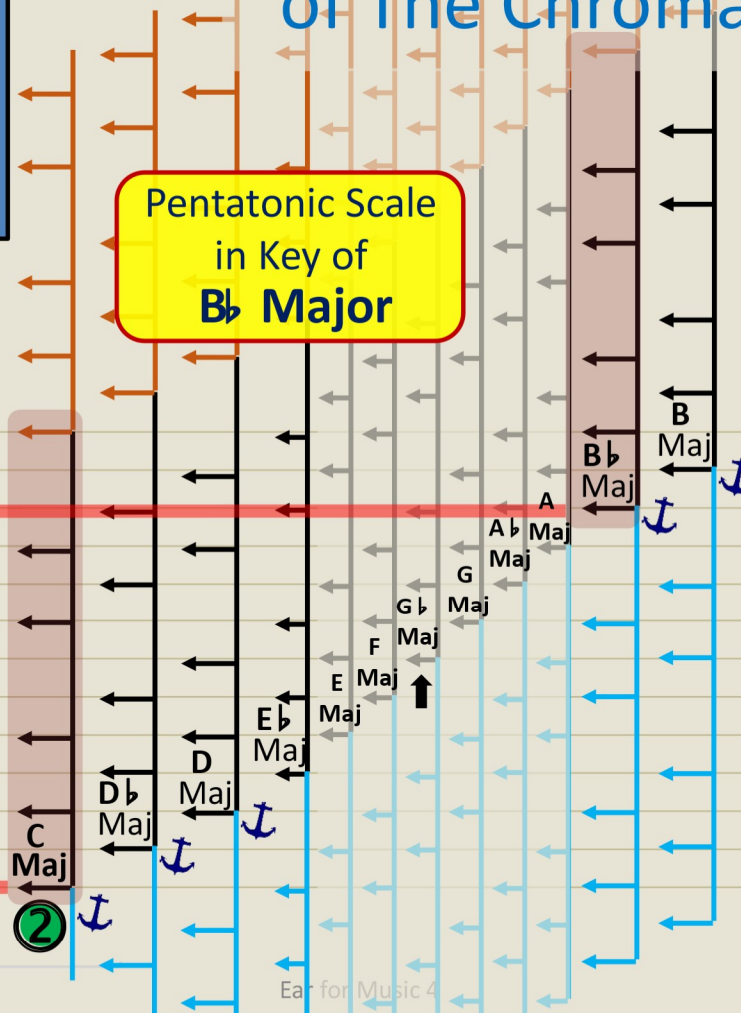
# The Pentatonic (5 note) Subscales of The Chromatic Scale: 12 Keys

Note	MIDI	f	Chromatic Scale
C#/D $\flat$ 6	85	1108.7	
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C#/D $\flat$ 5	73	554.4	
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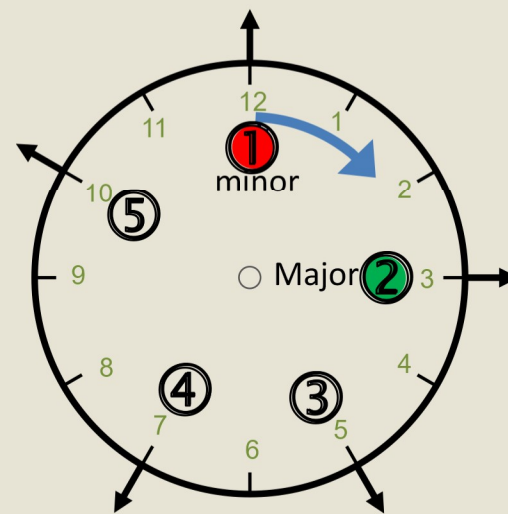
The Pentatonic Major Scale in 12 Keys →

Pentatonic Scale in Key of B $\flat$  Major

Pentatonic Scale in Key of C Major



- ① minor Pentatonic Scale
- ② Major Pentatonic Scale



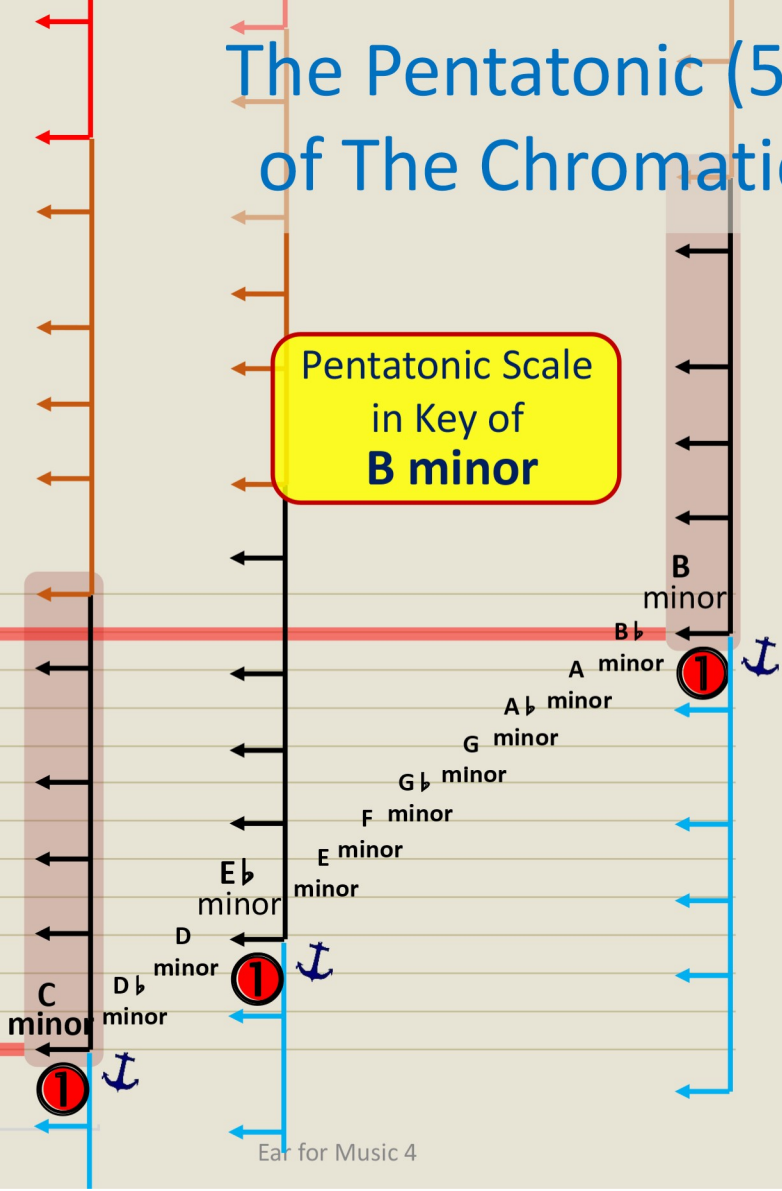
# The Pentatonic (5 note) Subscales of The Chromatic Scale: 12 Keys

Note	MIDI	<i>f</i>	Chromatic Scale
C#/D♭ 6	85	1108.7	
C 6	84	1046.5	
B 5	77	658.5	
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>B 4</b>	<b>71</b>	<b>493.9</b>	
A#/B♭ 4	70	466.2	
A 4	69	440	
G#/A♭ 4	68	415.3	
G 4	67	391.9	
F#/G♭ 4	66	370.0	
F 4	65	349.2	
E 4	64	329.6	
D#/E♭ 4	63	311.1	
D 4	62	293.7	
C#/D♭ 4	61	277.2	
<b>C 4</b>	<b>60</b>	<b>261.6</b>	
B 3	59	246.9	

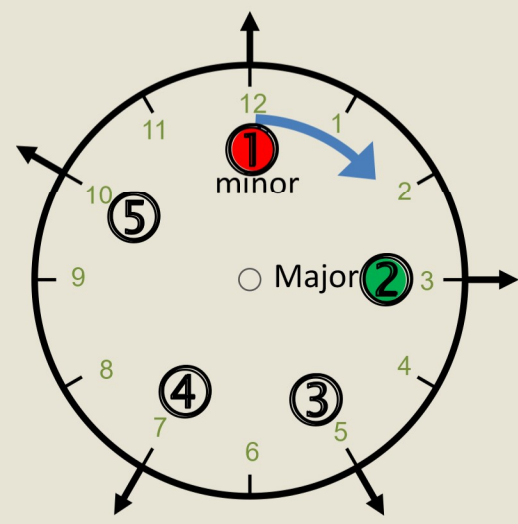
The Pentatonic Minor Scale also has 12 Keys →

Pentatonic Scale in Key of **C minor**

Pentatonic Scale in Key of **B minor**



- ① minor Pentatonic Scale
- ② Major Pentatonic Scale

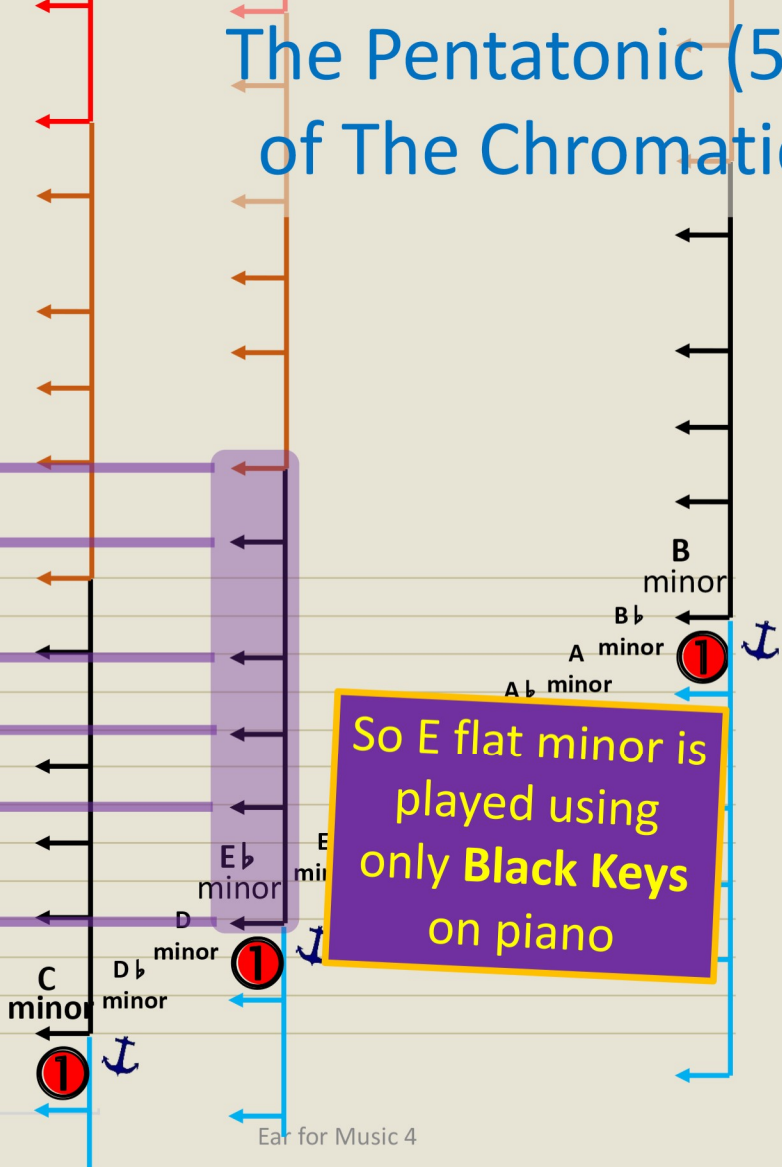




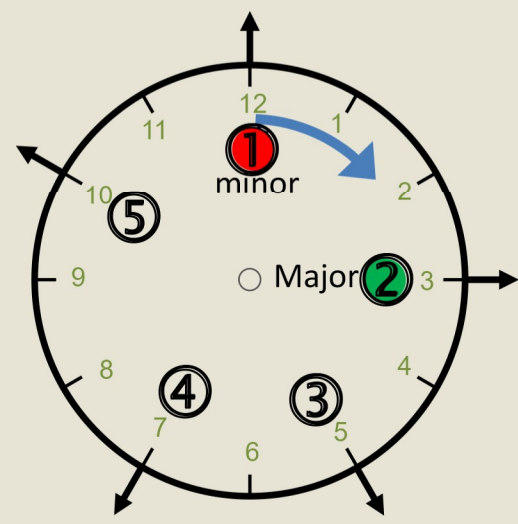
# The Pentatonic (5 note) Subscales of The Chromatic Scale: 12 Keys

The Pentatonic Minor Scale also has 12 Keys →

Note	MIDI	f	Chromatic Scale
C#/D♭ 6	85	1108.7	
C 6	84	1046.5	
B 5	79	987.6	
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	
G#/A♭ 4	68	415.3	
G 4	67	392.0	
F#/G♭ 4	66	370.0	
F 4	65	349.2	
E 4	64	329.6	
D#/E♭ 4	63	311.1	
D 4	62	293.7	
C#/D♭ 4	61	277.2	
C 4	60	261.6	
B 3	59	246.9	



- ① minor Pentatonic Scale
- ② Major Pentatonic Scale



# The Pentatonic (5 note) Subscales of The Chromatic Scale: **Relative Keys**

Note	MIDI	<i>f</i>	Chromatic Scale
C#/D $\flat$ 6	85	1108.7	
C 6	84	1046.5	
B 5	83	987.8	
A#/B $\flat$ 5	82	932.3	
A 5	81	880	
G#/A $\flat$ 5	80	830.6	
G 5	79	784.0	
F#/G $\flat$ 5	78	740.0	
F 5	77	698.5	
E 5	76	659.3	
D#/E $\flat$ 5	75	622.3	
D 5	74	587.3	
C#/D $\flat$ 5	73	554.4	
C 5	72	523.3	
B 4	71	493.9	
A#/B $\flat$ 4	70	466.2	
A 4	69	440	
G#/A $\flat$ 4	68	415.3	
G 4	67	392.0	
F#/G $\flat$ 4	66	370.0	
F 4	65	349.2	
E 4	64	329.6	
D#/E $\flat$ 4	63	311.1	
D 4	62	293.7	
C#/D $\flat$ 4	61	277.2	
C 4	60	261.6	
B 3	59	246.9	

- ① **minor** Pentatonic Scale
- ② **Major** Pentatonic Scale

If these 2 scales share the exact same notes ... then what is the difference between them?

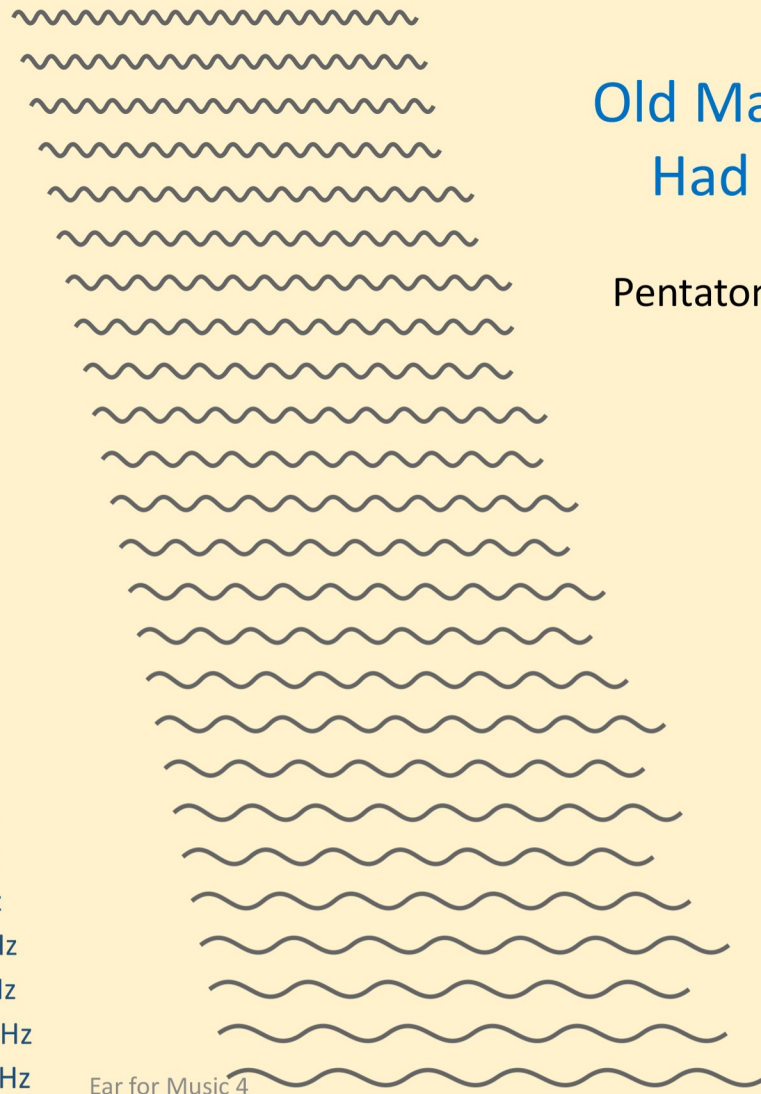
The “anchor notes” are different. These are called the **Tonic Notes**. They form the “Pitch Center” of the musical piece

**E minor**      **G Major**

Pentatonic G Major Scale



f79	G5	783.99Hz
f78	F#5	739.99Hz
f77	F5	698.46Hz
f76	E5	659.26Hz
f75	D#5	622.25Hz
f74	D5	587.33Hz
f73	C#5	554.37Hz
f72	C5	523.25Hz
f71	B4	493.88Hz
f70	A#4	466.16Hz
f69	A4	440.00Hz
f68	G#4	415.30Hz
f67	G4	392.00Hz
f66	F#4	369.99Hz
f65	F4	349.23Hz
f64	E4	329.63Hz
f63	D#4	311.13Hz
f62	D4	293.66Hz
f61	C#4	277.18Hz
f60	C4	261.63Hz
f59	B3	246.94Hz
f58	A#3	233.08Hz
f57	A3	220.00Hz
f56	G#3	207.65Hz
f55	G3	196.00Hz



Old MacDonald  
Had a Farm  
in  
Pentatonic G Major

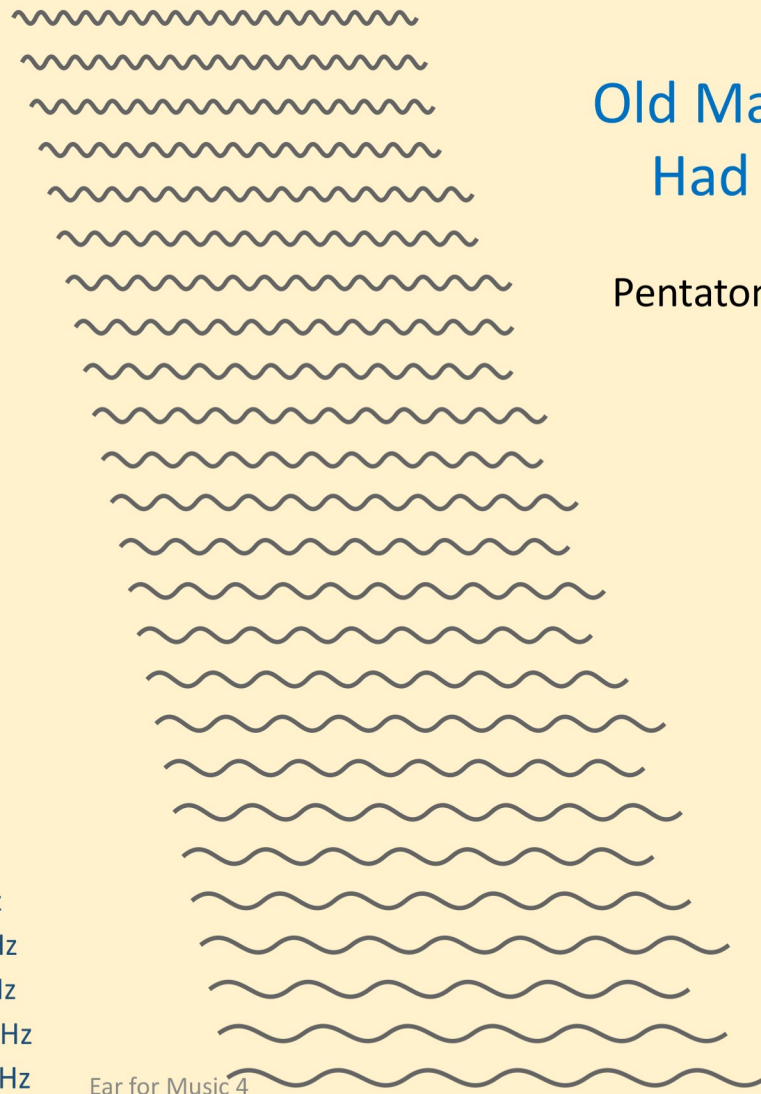
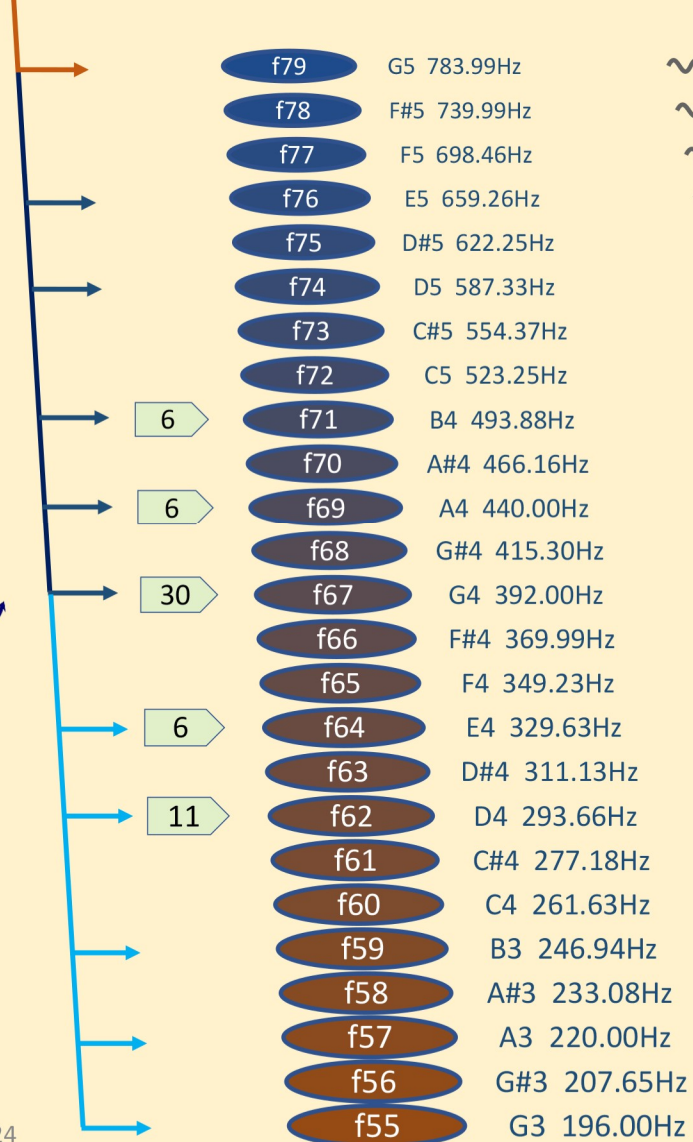






# Old MacDonald Had a Farm in Pentatonic G Major

Pentatonic  
G Major  
Scale

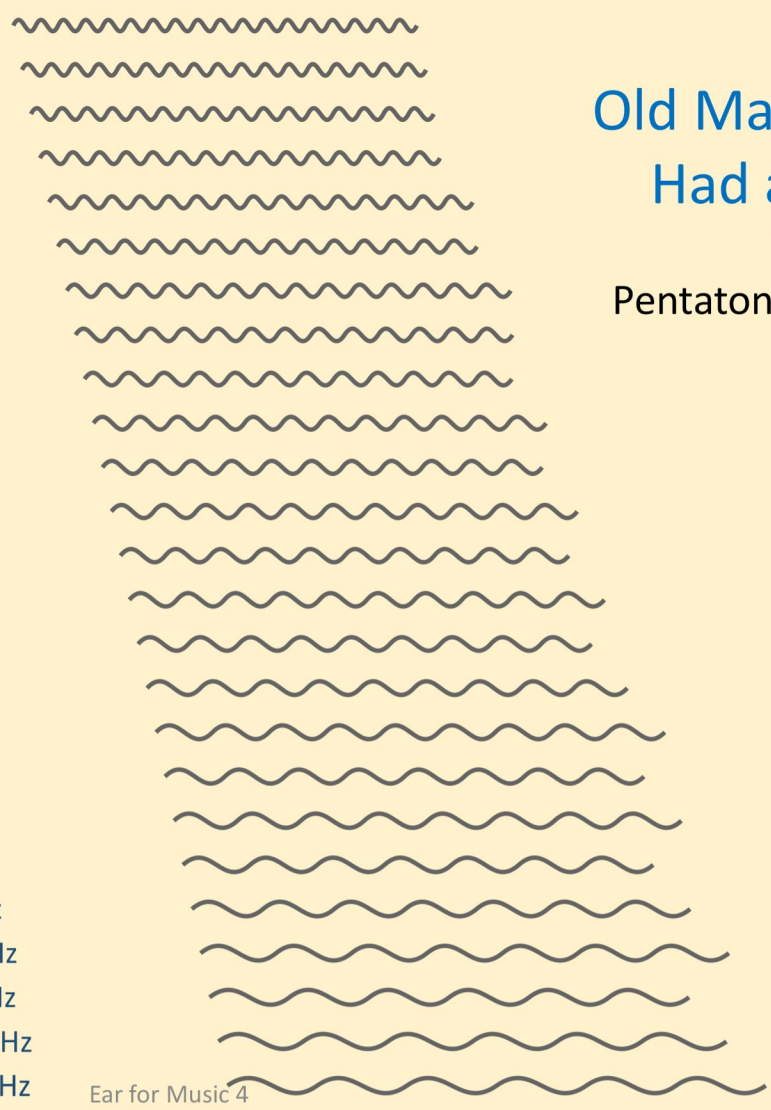
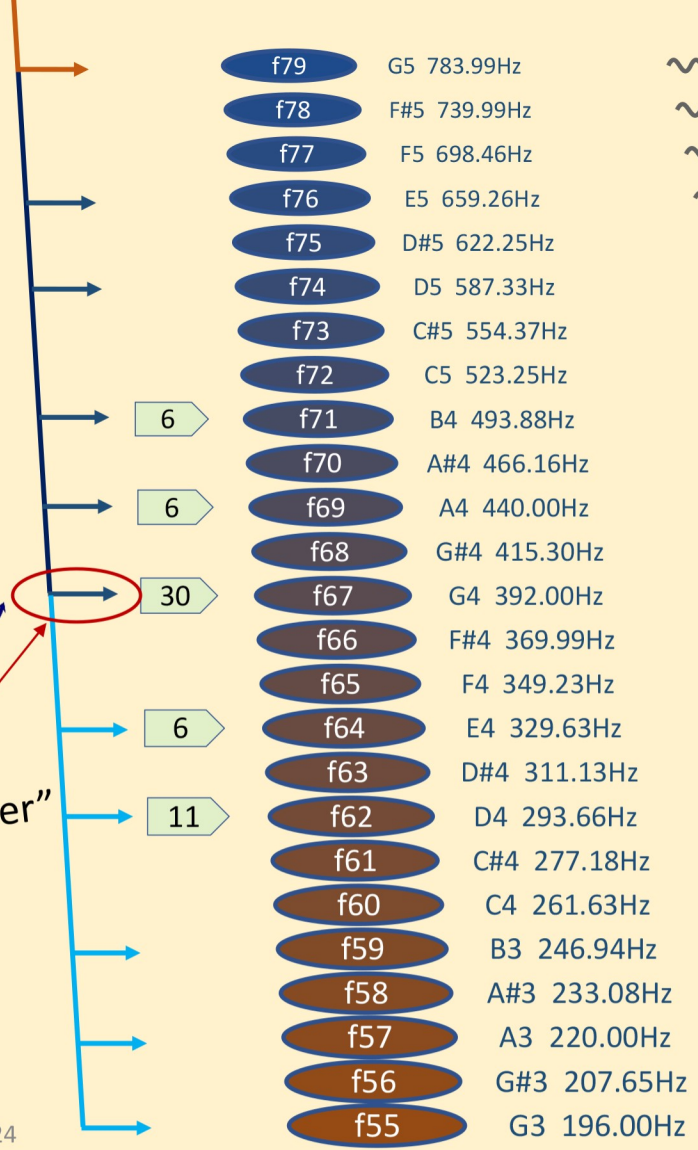


# Old MacDonald Had a Farm in Pentatonic G Major

Pentatonic  
G Major  
Scale

"Tonic"

"Pitch Center"

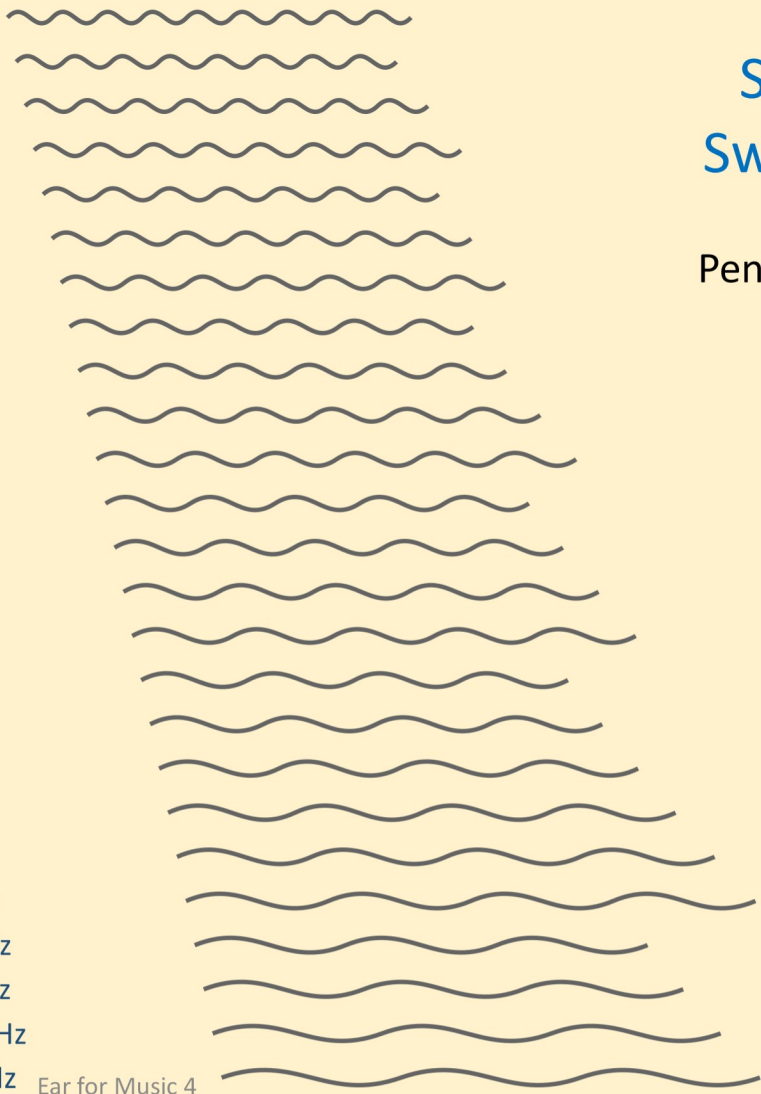




Pentatonic G Major Scale



f67	G4	392.00Hz
f66	F#4	369.99Hz
f65	F4	349.23Hz
f64	E4	329.63Hz
f63	D#4	311.13Hz
f62	D4	293.66Hz
f61	C#4	277.18Hz
f60	C4	261.63Hz
f59	B3	246.94Hz
f58	A#3	233.08Hz
f57	A3	220.00Hz
f56	G#3	207.65Hz
f55	G3	196.00Hz
f54	F#3	185.00Hz
f53	F3	174.61Hz
f52	E3	164.81Hz
f51	D#3	155.56Hz
f50	D3	146.83Hz
f49	C#3	138.59Hz
f48	C3	130.81Hz
f47	B2	123.47Hz
f46	A#2	116.54Hz
f45	A2	110.00Hz
f44	G#2	103.83Hz
f43	G2	98.00Hz



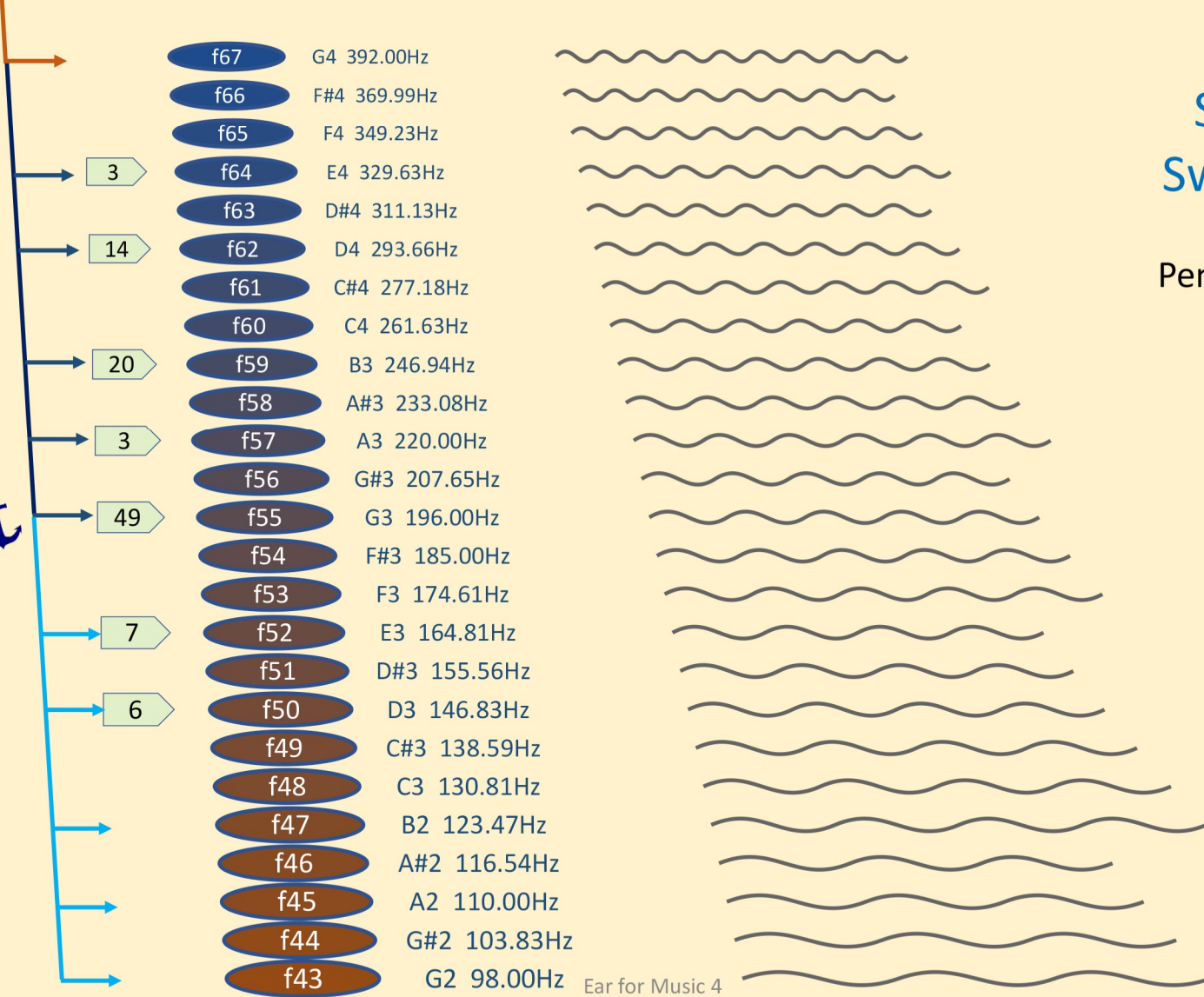
Swing Low  
Sweet Chariot  
in  
Pentatonic G Major





# Swing Low Sweet Chariot in Pentatonic G Major

Pentatonic  
G Major  
Scale

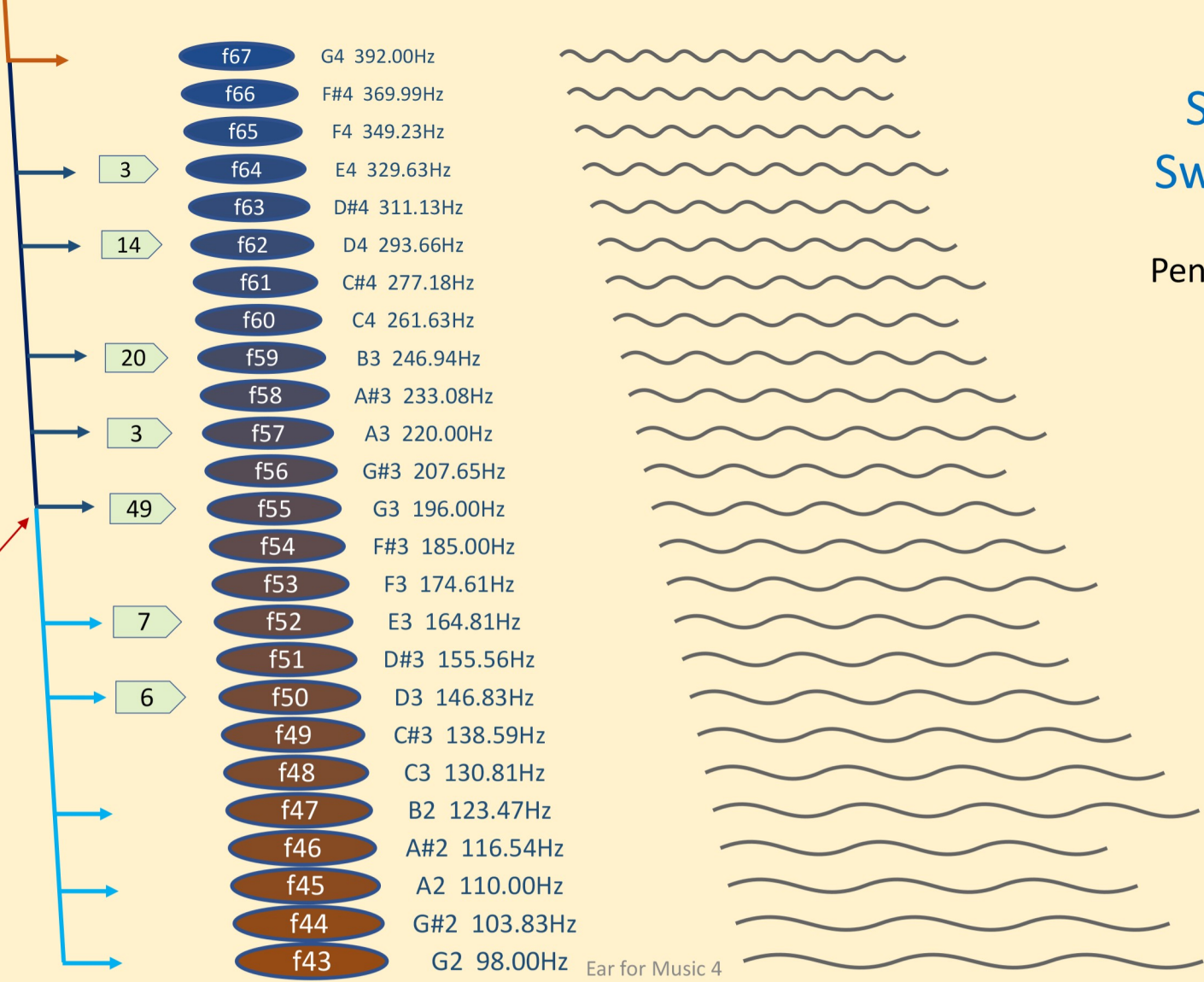


# Swing Low Sweet Chariot in Pentatonic G Major

Pentatonic  
G Major  
Scale

"Tonic"

Tonal Center



# Subscales of The Chromatic Scale

Note	MIDI	<i>f</i>	Chromatic Scale
C#/D $\flat$ 6	85	1108.7	
C 6	84	1046.5	
B 5	83	987.8	
A#/B $\flat$ 5	82	932.3	
A 5	81	880	
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G 5	79	784.0	
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F 5	77	698.5	
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D 5	74	587.3	
C#/D $\flat$ 5	73	554.4	
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B 4	71	493.9	
A#/B $\flat$ 4	70	466.2	
A 4	69	440	
G#/A $\flat$ 4	68	415.3	
G 4	67	392.0	
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F 4	65	349.2	
E 4	64	329.6	
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D 4	62	293.7	
C#/D $\flat$ 4	61	277.2	
C 4	60	261.6	
B 3	59	246.9	

Traditional Country Music Blues

Classical Pop Rock

**Pentatonic**  
**Heptatonic**  
(Includes Diatonic)

Used for Jazz?

m Notes	Patterns	Keys	Total Scales
1	1	12	12
2	11	12	132
3	55	12	660
4	165	12	1980
5	330	12	3960
6	462	12	5544
7	462	12	5544
8	330	12	3960
9	165	12	1980
10	55	12	660
11	11	12	132
12	1	12	12

Only a tiny fraction are of use!

Only ~20 are useful



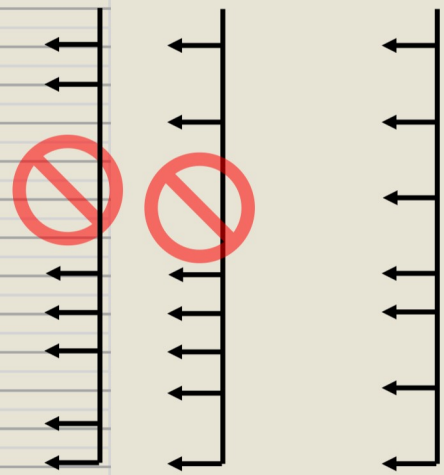
# The Heptatonic (7 note) Subscales of The Chromatic Scale

There are **462**  $m=7$  Patterns belonging to 66 families

Note	MIDI	$f$	Chromatic Scale
C#/D $\flat$ 6	85	1108.7	
C 6	84	1046.5	
B 5	83	987.8	
A#/B $\flat$ 5	82	932.3	
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C#/D $\flat$ 4	61	277.2	
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B 3	59	246.9	

But most are dumb like these

when there are patterns like this



If we require reasonably uniform coverage of the 12 notes of the Chromatic Scale, only 3 main Pattern families emerge...





# The Diatonic (7 note) Subscales of The Chromatic Scale:

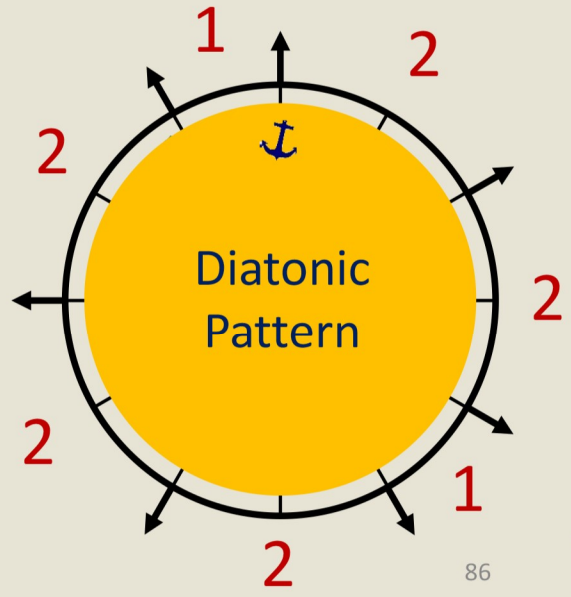
The Most Uniform Coverage of the Octave

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“The” Diatonic Family Pattern

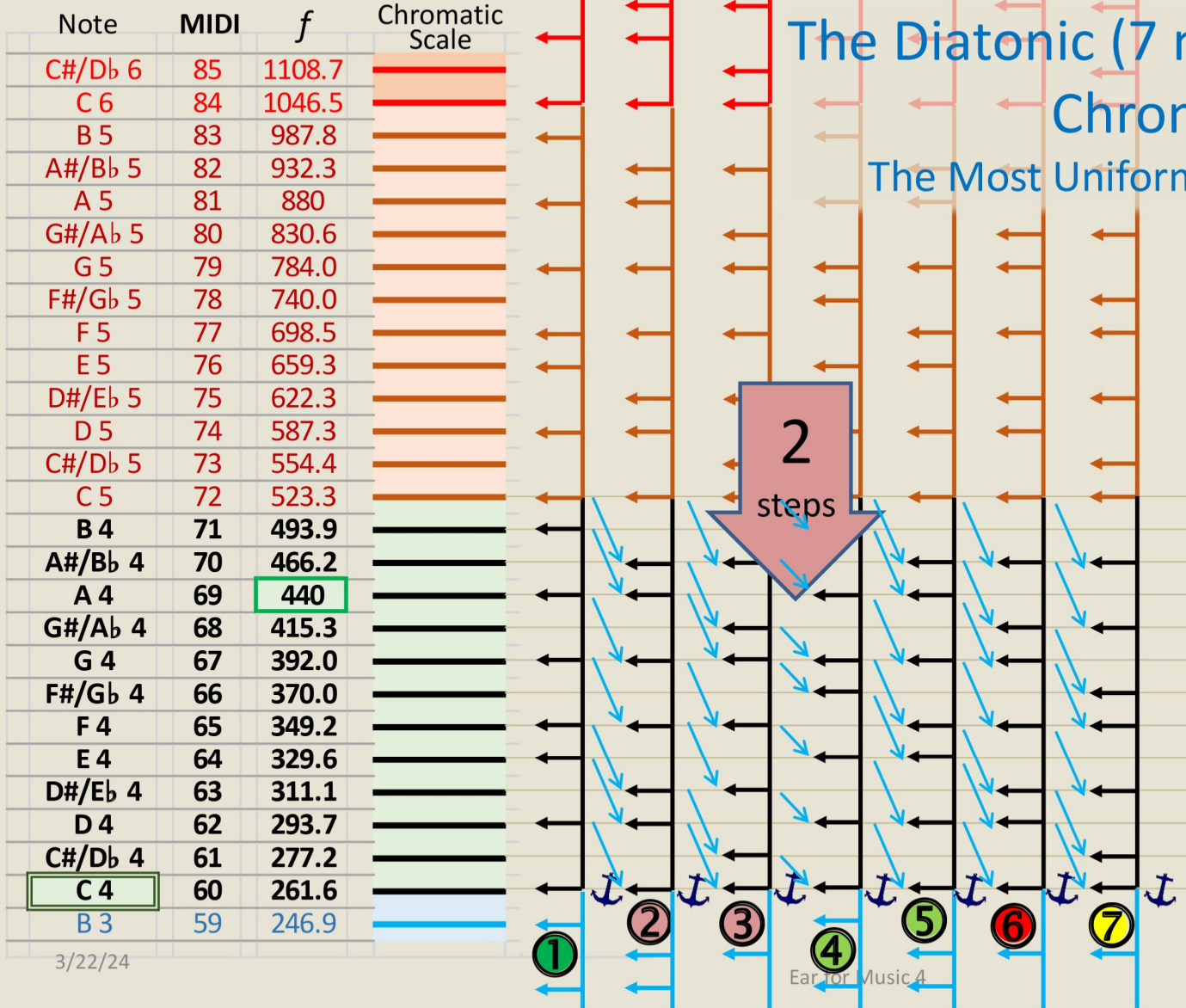
Heptatonic Pattern Family #1: “Diatonic”

Greek *dia-* “through or across”

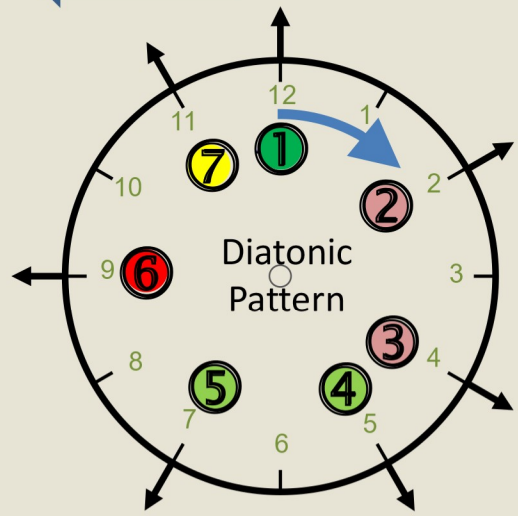


# The Diatonic (7 note) Subscales of The Chromatic Scale:

The Most Uniform Coverage of the Octave



“The” Diatonic Family Modes

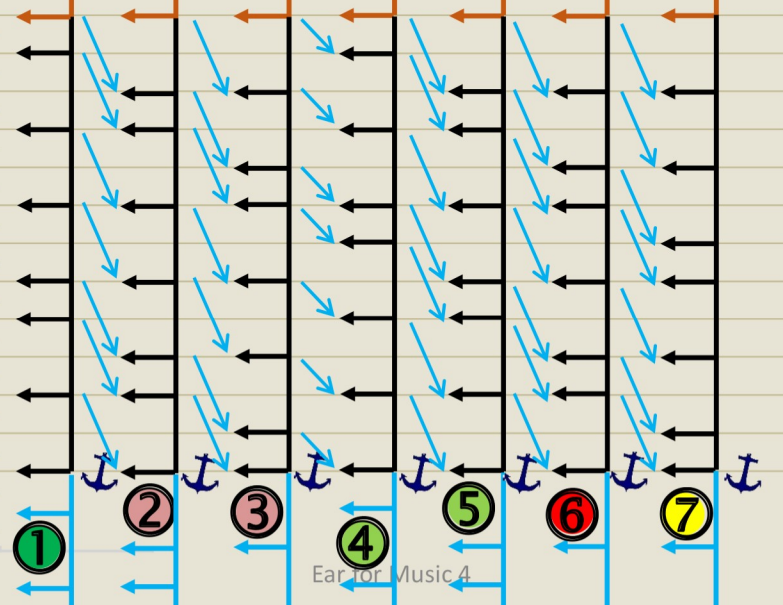


# The Diatonic (7 note) Subscales of The Chromatic Scale:

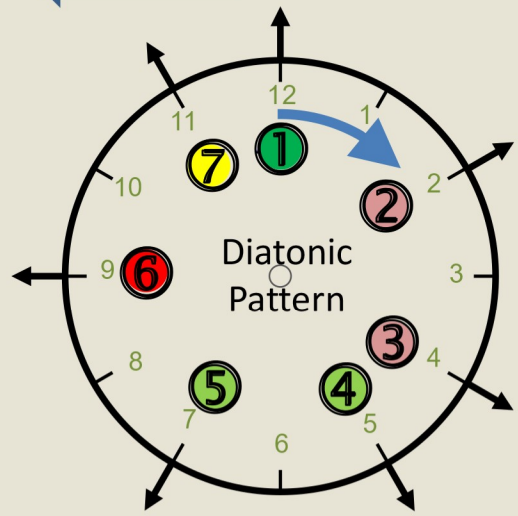
The Most Uniform Coverage of the Octave

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D 4	62	293.7	
C#/D $\flat$ 4	61	277.2	
C 4	60	261.6	
B 3	59	246.9	

These are the 7 "Modes" of the Diatonic Scale, starting with the Major mode



"The" Diatonic Family Modes





# The Diatonic (7 note) Subscales of The Chromatic Scale:

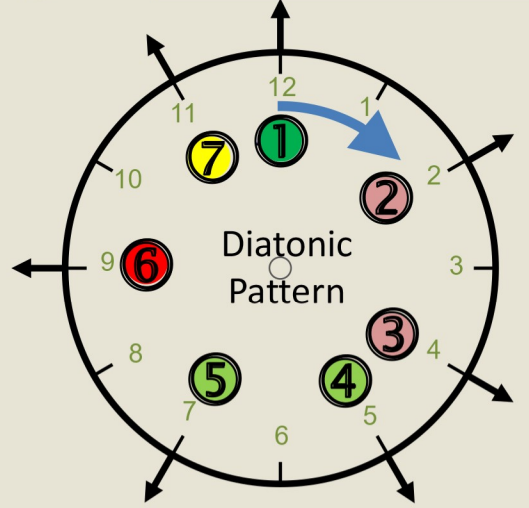
The Most Uniform Coverage of the Octave

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G 4	67	392.0	
F#/G $\flat$ 4	66	370.0	
F 4	65	349.2	
E 4	64	329.6	4th Step
D#/E $\flat$ 4	63	311.1	
D 4	62	293.7	
C#/D $\flat$ 4	61	277.2	
C 4	60	261.6	
B 3	59	246.9	

“Natural Major” **① ④ ⑤** “Major” modes

**⑥ ② ③** “minor” modes

**⑦** Rare (sounds terrible)





Note	MIDI	<i>f</i>	Chromatic Scale
C#/D $\flat$ 6	85	1108.7	
C 6	84	1046.5	
B 5	83	987.8	
A#/B $\flat$ 5	82	932.3	
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F 4	65	349.2	
E 4	64	329.6	4th Step
D#/E $\flat$ 4	63	311.1	3rd Step
D 4	62	293.7	
C#/D $\flat$ 4	61	277.2	
C 4	60	261.6	
B 3	59	246.9	

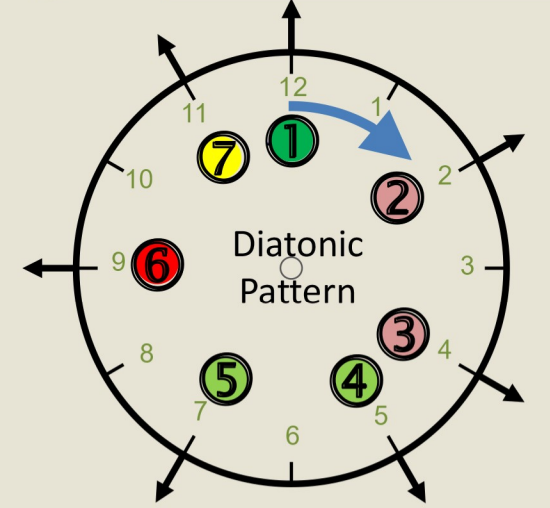
# The Diatonic (7 note) Subscales of The Chromatic Scale:

The Most Uniform Coverage of the Octave

“Natural Major” ① ④ ⑤ “Major” modes

“Natural minor” ⑥ ② ③ “minor” modes

⑦ Rare (sounds terrible)



# The Diatonic (7 note) Subscales of The Chromatic Scale:

The Most Uniform Coverage of the Octave

These 7 Modes have names:

1. **Ionian** (a.k.a. Natural Major)
2. **Dorian**
3. **Phrygian**
4. **Lydian**
5. **Mixolydian**
6. **Aeolian** (a.k.a. Natural minor)
7. **Locrian**

"Natural Major"

① ④ ⑤

"Major" modes

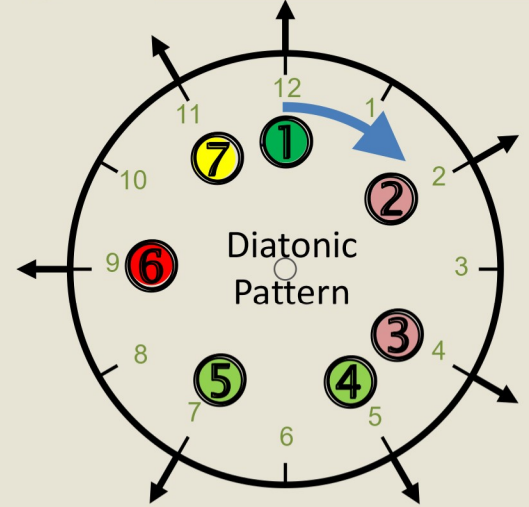
"Natural minor"

⑥ ② ③

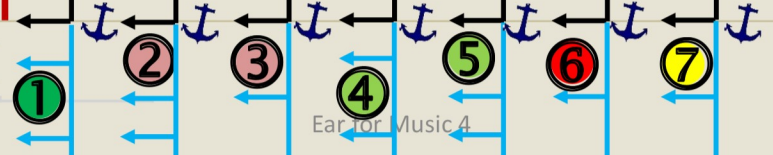
"minor" modes

⑦

Rare (sounds terrible)



Note	MIDI	f	Chromatic Scale
C#/D $\flat$ 6			
C 6			
B 5			
A#/B $\flat$ 5			
A 5			
G#/A $\flat$ 5			
G 5			
F#/G $\flat$ 5			
F 5			
E 5			
D#/E $\flat$ 5			
D 5			
C#/D $\flat$ 5			
C 5			
B 4			
A#/B $\flat$ 4			
A 4	69	440	
G#/A $\flat$ 4	68	415.3	
G 4	67	392.0	
F#/G $\flat$ 4	66	370.0	
F 4	65	349.2	
E 4	64	329.6	4th Step
D#/E $\flat$ 4	63	311.1	3rd Step
D 4	62	293.7	
C#/D $\flat$ 4	61	277.2	
C 4	60	261.6	
B 3	59	246.9	



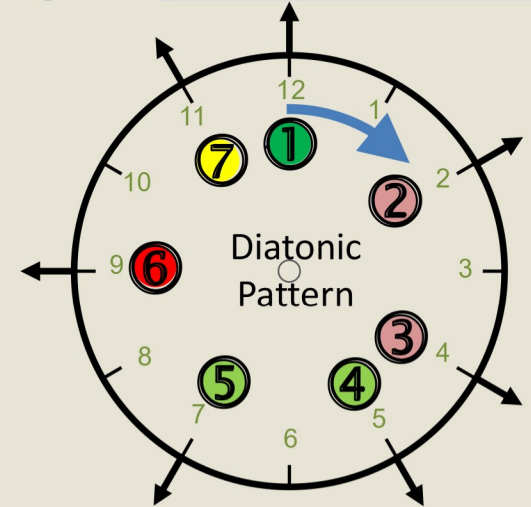
# The Diatonic (7 note) Subscales of The Chromatic Scale: 12 Keys

Note	MIDI	<i>f</i>	Chromatic Scale
C#/D $\flat$ 6	85	1108.7	
C 6	84	1046.5	
B 5	83	987.8	
A#/B $\flat$ 5	82	932.3	
A 5	81	880	
G#/A $\flat$ 5	80	830.6	
G 5	79	784.0	
F#/G $\flat$ 5	78	740.0	
F 5	77	698.5	
E 5	76	659.3	
D#/E $\flat$ 5	75	622.3	
D 5	74	587.3	
C#/D $\flat$ 5	73	554.4	
C 5	72	523.3	
B 4	71	493.9	
A#/B $\flat$ 4	70	466.2	
A 4	69	440	
G#/A $\flat$ 4	68	415.3	
G 4	67	392.0	
F#/G $\flat$ 4	66	370.0	
F 4	65	349.2	
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D 4	62	293.7	
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C 4	60	261.6	
B 3	59	246.9	

① ④ ⑤ "Major" modes

⑥ ② ③ "minor" modes

⑦ Rare (sounds terrible)

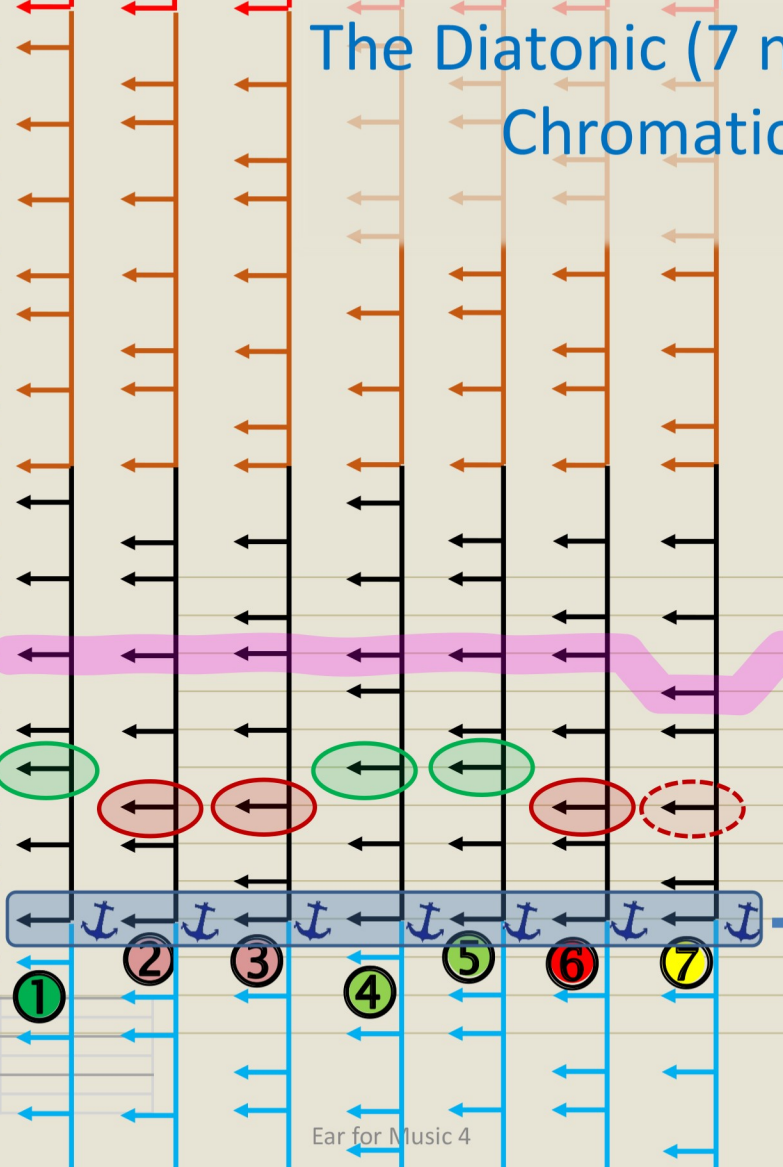




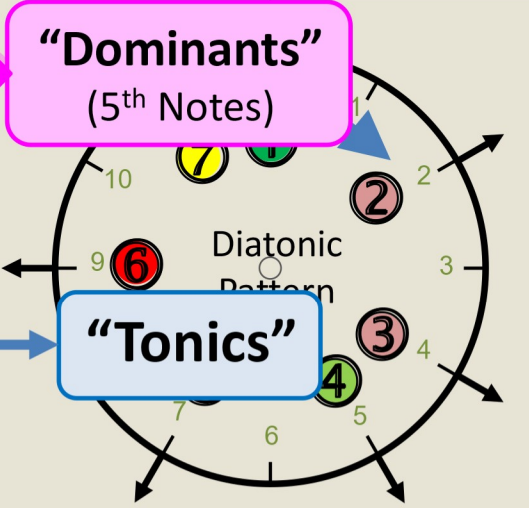
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D#/E $\flat$ 4	63	311.1	
D 4	62	293.7	
C#/D $\flat$ 4	61	277.2	
C 4	60	261.6	
B 3	59	246.9	

Key of E flat



- ① ④ ⑤ "Major" modes
- ⑥ ② ③ "minor" modes
- ⑦ Rare (sounds terrible)





# The Diatonic (7 note) Subscales of The Chromatic Scale: 12 Keys

There are **12** Keys:  
 C D♭ D E♭ E F G♭ G A B♭ B  
 for each of **7** Modes  
 for a total of  $7 \times 12 =$   
**84** Diatonic Scales

Note	MIDI	f	Chromatic Scale
C#/D♭ 6	85	1109.7	
C 6			
B 5			
A#/B♭ 5			
A 5			
G#/A♭ 5			
G 5			
F#/G♭ 5			
F 5			
E 5			
D#/E♭ 5			
D 5			
C#/D♭ 5			
C 5			
B 4			
A#/B♭ 4	70	466.2	
A 4	69	440	
G#/A♭ 4	68	415.3	
G 4	67	392.0	
F#/G♭ 4	66	370.0	
F 4			
E 4		329.6	
D#/E♭ 4	63	311.1	
D 4	62	293.7	
C#/D♭ 4	61	277.2	
C 4	60	261.6	
B 3	59	246.9	

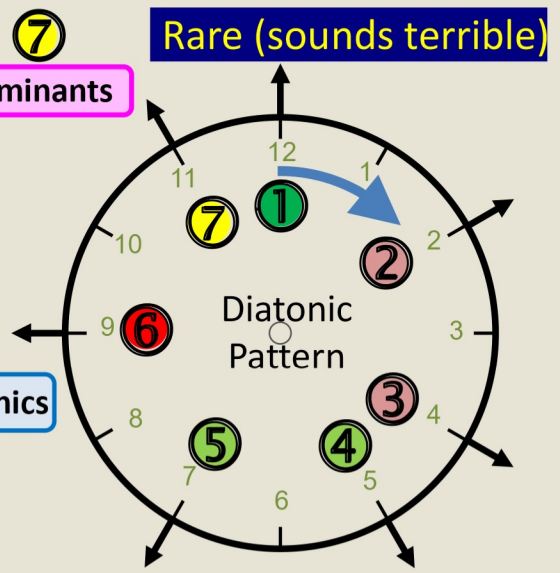
Key of E flat



- ④ ⑤ "Major" modes
- ⑥ ② ③ "minor" modes
- ⑦ Rare (sounds terrible)

Dominants

Tonics



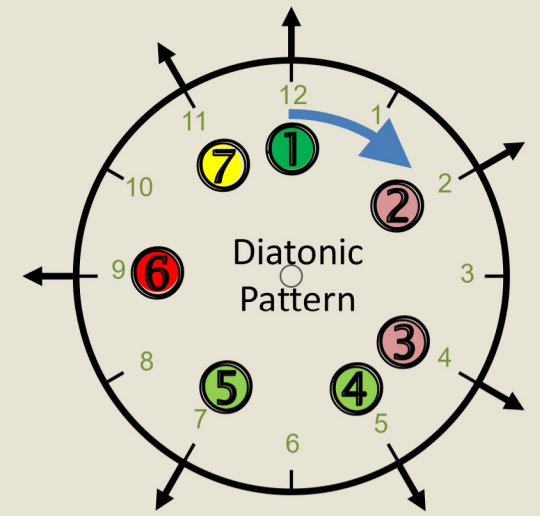
# The Diatonic (7 note) Subscales of The Chromatic Scale:

## The Principal Modes

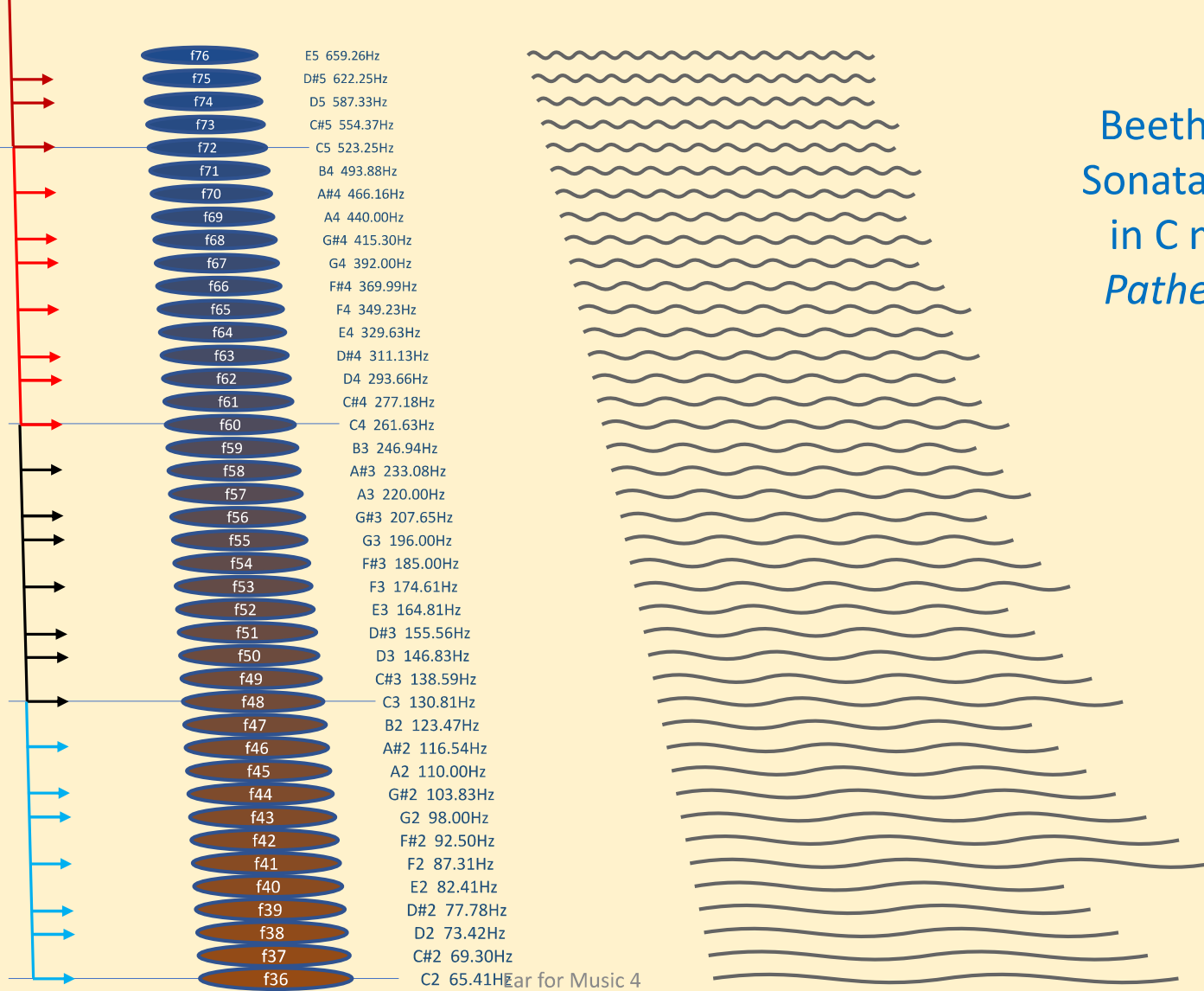
Note	MIDI	<i>f</i>	Chromatic Scale
C#/D $\flat$ 6	85	1108.7	
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B 5	83	987.8	
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A 5	81	880	
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G 5	79	784.0	
F#/G $\flat$ 5	78	740.0	
F 5	77	698.5	
E 5	76	659.3	
D#/E $\flat$ 5	75	622.3	
D 5	74	587.3	
C#/D $\flat$ 5	73	554.4	
C 5	72	523.3	
B 4	71	493.9	
A#/B $\flat$ 4	70	466.2	
A 4	69	440	
G#/A $\flat$ 4	68	415.3	
G 4	67	392.0	
F#/G $\flat$ 4	66	370.0	
F 4	65	349.2	
E 4	64	329.6	
D#/E $\flat$ 4	63	311.1	
D 4	62	293.7	
C#/D $\flat$ 4	61	277.2	
C 4	60	261.6	
B 3	59	246.9	

These are the Biggies

- ① "Natural Major" mode
- ⑥ "Natural minor" mode



# C minor Diatonic Scale

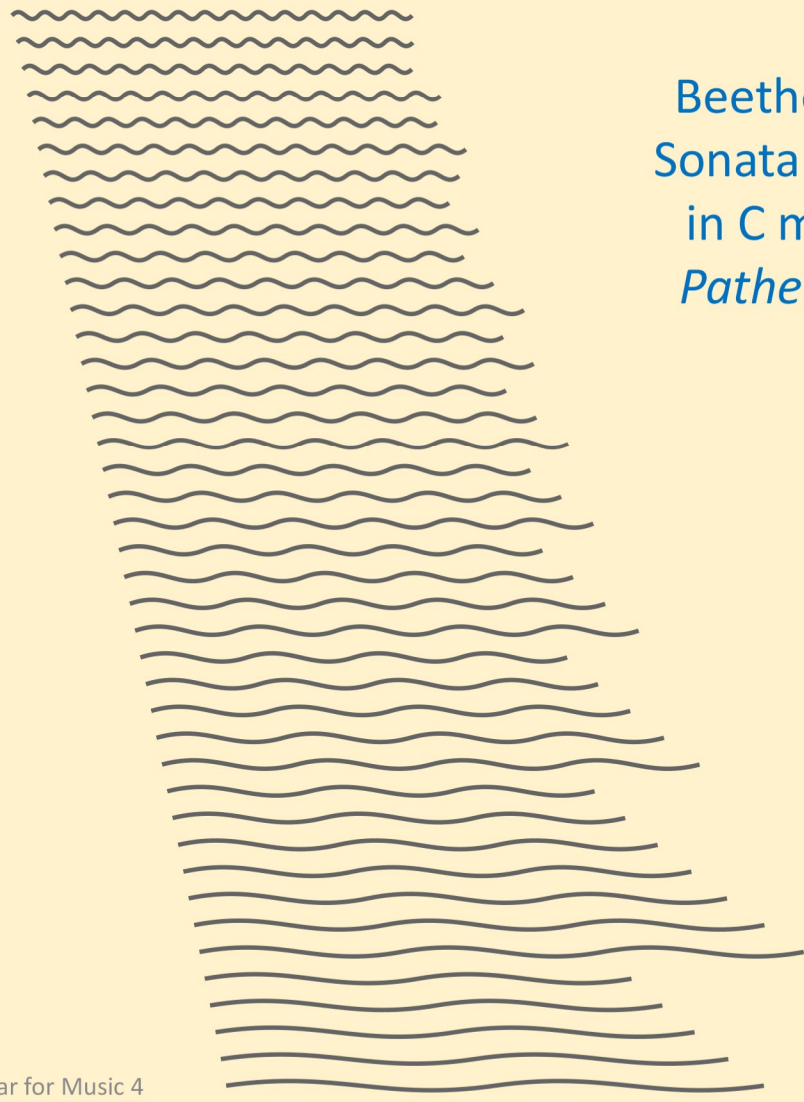
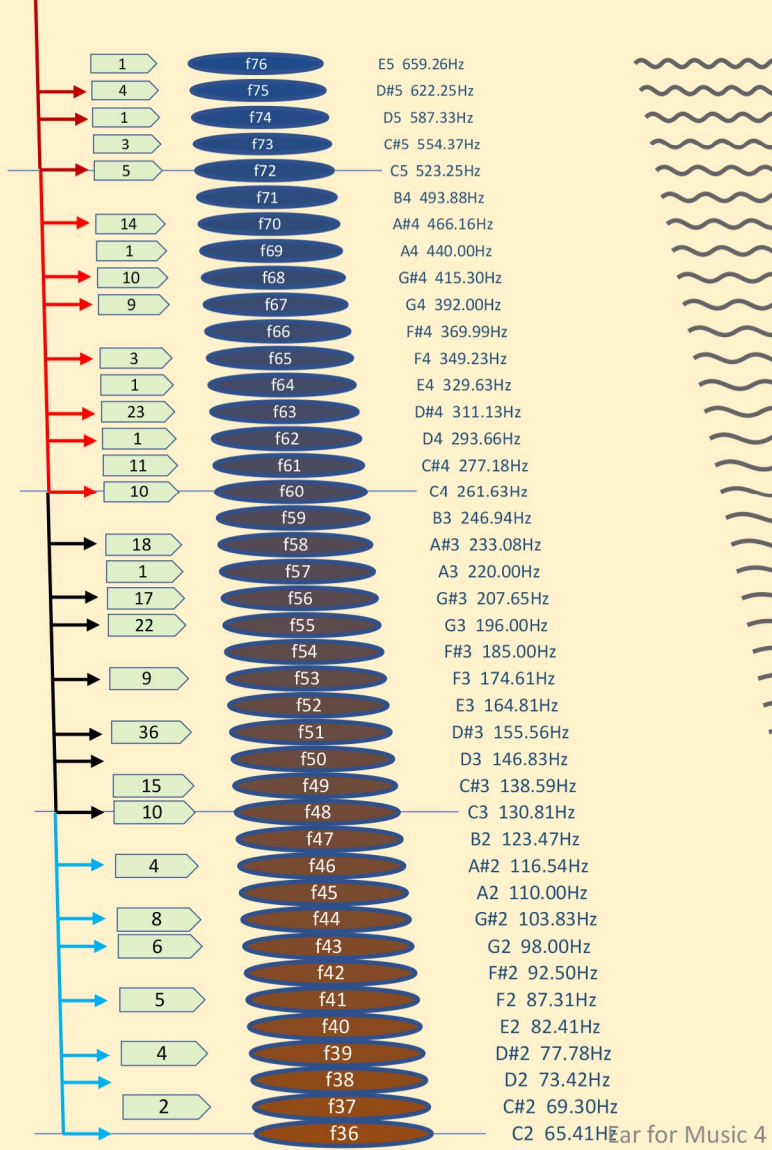


# Beethoven Sonata No. 8 in C minor Pathetique





# C minor Diatonic Scale



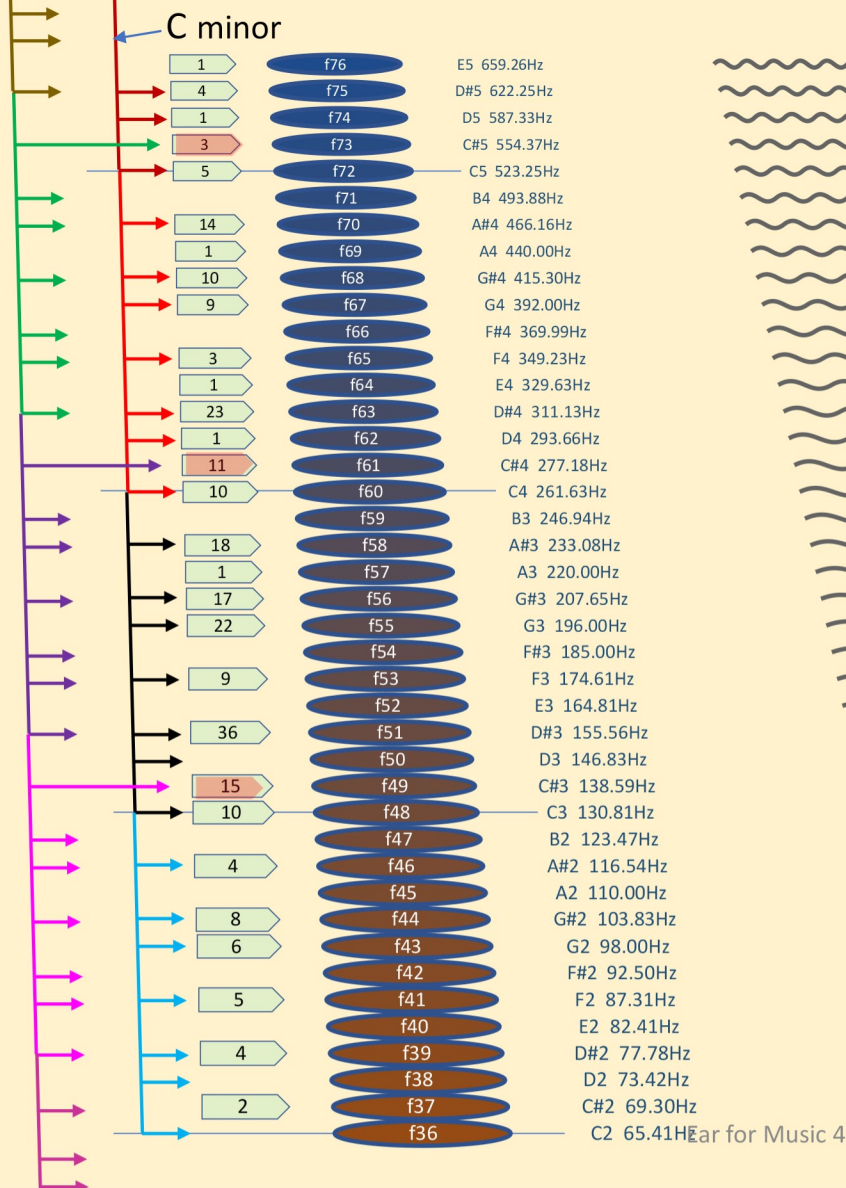
# Beethoven Sonata No. 8 in C minor *Pathétique*





# Beethoven Sonata No. 8 in C minor *Pathetique* [first 60 sec]

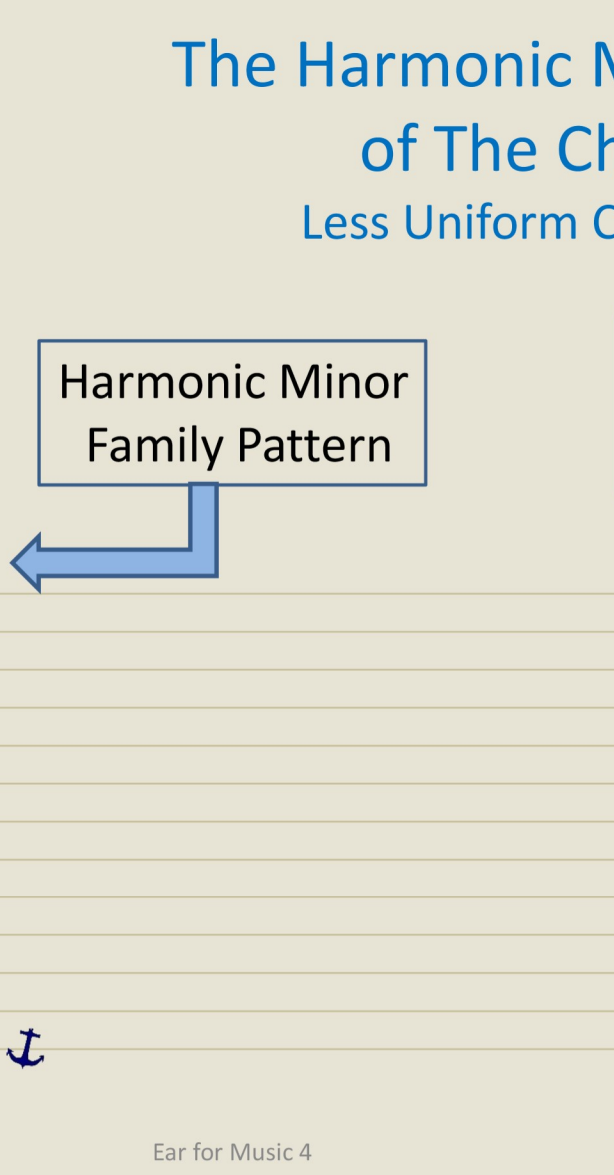
E flat  
minor  
Diatonic  
Scale



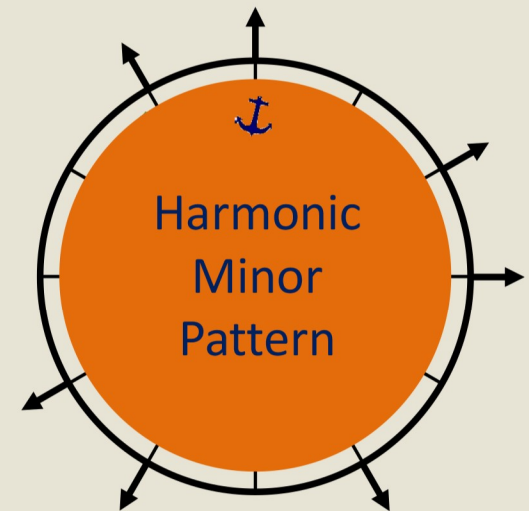
Several of the notes played  
DO NOT belong to the  
C minor Scale!  
Beethoven changed his scale  
along the way....

# The Harmonic Minor Scale Subscales of The Chromatic Scale: Less Uniform Coverage of the Octave

Note	MIDI	<i>f</i>	Chromatic Scale
C#/D $\flat$ 6	85	1108.7	
C 6	84	1046.5	
B 5	83	987.8	
A#/B $\flat$ 5	82	932.3	
A 5	81	880	
G#/A $\flat$ 5	80	830.6	
G 5	79	784.0	
F#/G $\flat$ 5	78	740.0	
F 5	77	698.5	
E 5	76	659.3	
D#/E $\flat$ 5	75	622.3	
D 5	74	587.3	
C#/D $\flat$ 5	73	554.4	
C 5	72	523.3	
B 4	71	493.9	
A#/B $\flat$ 4	70	466.2	
A 4	69	440	
G#/A $\flat$ 4	68	415.3	
G 4	67	392.0	
F#/G $\flat$ 4	66	370.0	
F 4	65	349.2	
E 4	64	329.6	
D#/E $\flat$ 4	63	311.1	
D 4	62	293.7	
C#/D $\flat$ 4	61	277.2	
C 4	60	261.6	
B 3	59	246.9	



Heptatonic Pattern  
Family #2:  
**"Harmonic Minor"**



# The Harmonic Minor Scale Subscales of The Chromatic Scale:

## Less Uniform Coverage of the Octave

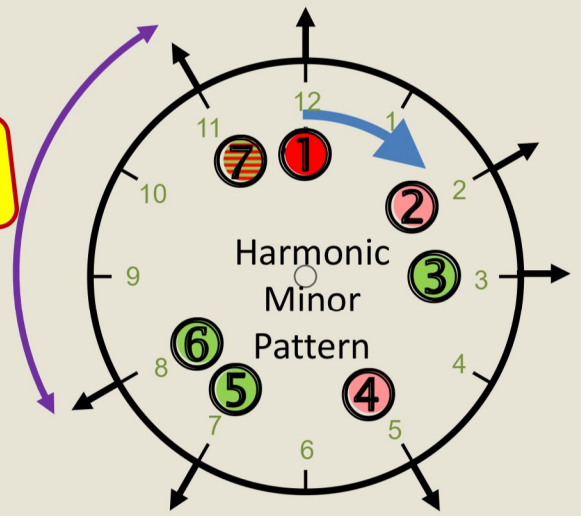
Note	MIDI	<i>f</i>	Chromatic Scale
C#/D $\flat$ 6	85	1108.7	
C 6	84	1046.5	
B 5	83	987.8	
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D 4	62	293.7	
C#/D $\flat$ 4	61	277.2	
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B 3	59	246.9	



Harmonic Minor Family Pattern

Heptatonic Pattern Family #2: "Harmonic Minor"

Huge gap





# The Melodic Minor Scale Subscales of the Chromatic Scale:

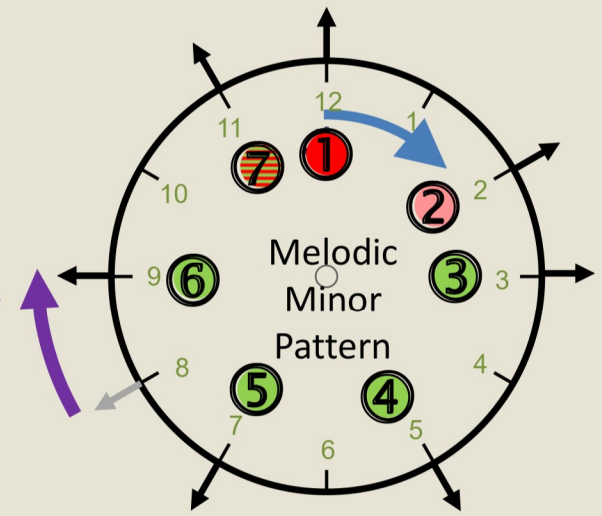
Also Less Uniform Coverage of the Octave

Note	MIDI	<i>f</i>	Chromatic Scale
C#/D $\flat$ 6	85	1108.7	
C 6	84	1046.5	
B 5	83	987.8	
A#/B $\flat$ 5	82	932.3	
A 5	81	880	
G#/A $\flat$ 5	80	830.6	
G 5	79	784.0	
F#/G $\flat$ 5	78	740.0	
F 5	77	698.5	
E 5	76	659.3	
D#/E $\flat$ 5	75	622.3	
D 5	74	587.3	
C#/D $\flat$ 5	73	554.4	
C 5	72	523.3	
B 4	71	493.9	
A#/B $\flat$ 4	70	466.2	
A 4	69	440	
G#/A $\flat$ 4	68	415.3	
G 4	67	392.0	
F#/G $\flat$ 4	66	370.0	
F 4	65	349.2	
E 4	64	329.6	
D#/E $\flat$ 4	63	311.1	
D 4	62	293.7	
C#/D $\flat$ 4	61	277.2	
C 4	60	261.6	
B 3	59	246.9	

Melodic Minor Family Pattern

Heptatonic Pattern Family #3: "Melodic Minor"

Only Change from Harmonic Minor





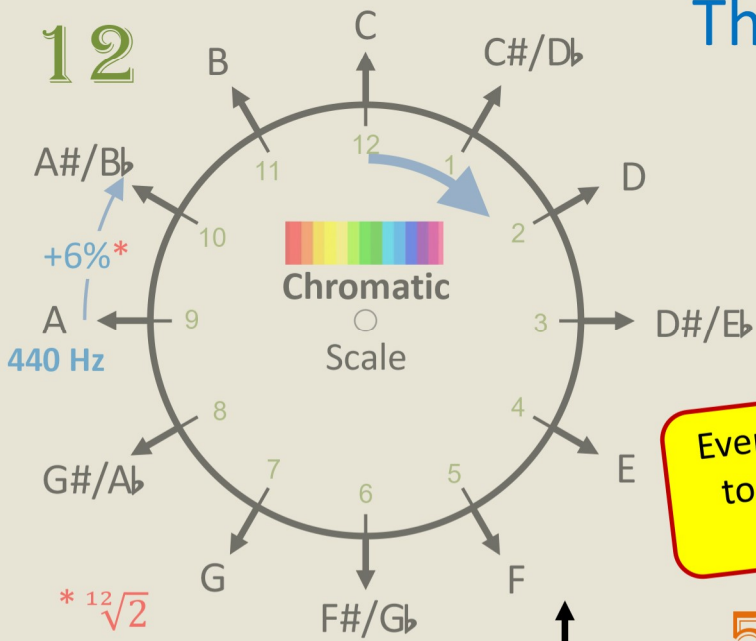


After the Apocalypse.....  
What if you were called upon  
to reconstruct modern music?



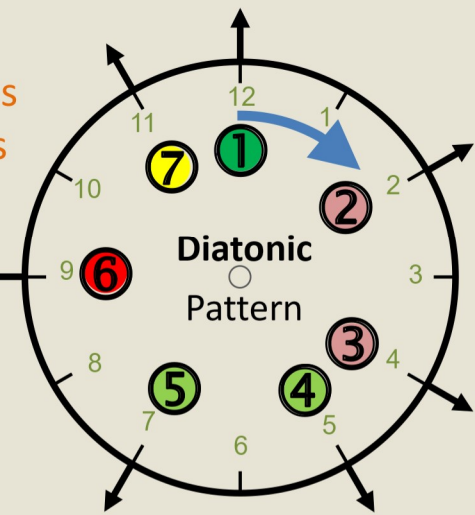
# The Chromatic Scale and Its Main Subscales

12



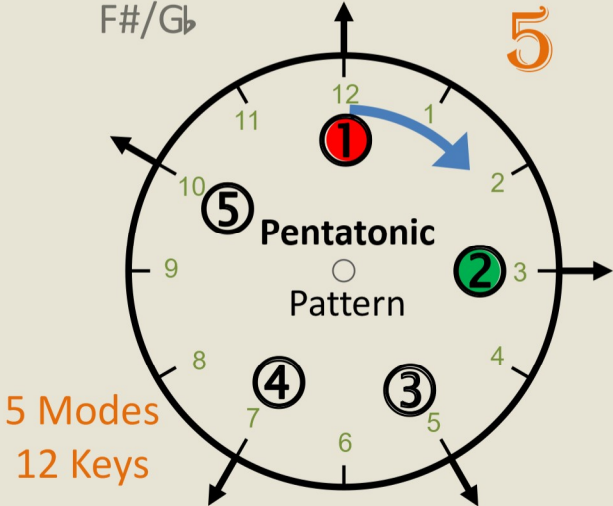
7 Modes  
12 Keys

Everything you need to know  
to re-create modern music  
-- sort of

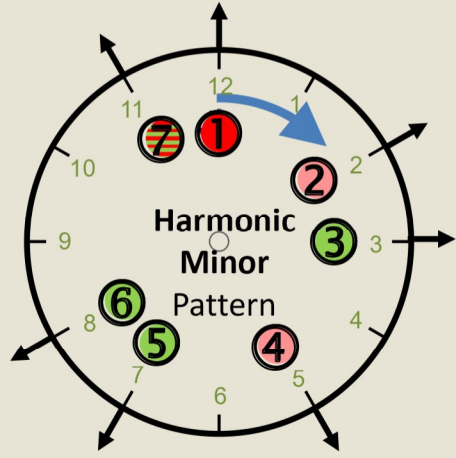


Biggie!

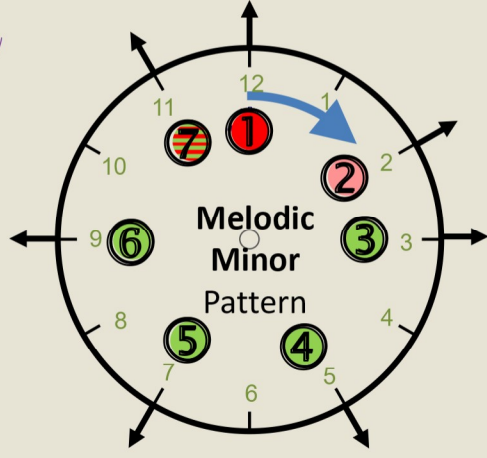
- Modes
- M Major
  - m minor



5 Modes  
12 Keys



Ear for Music 4



3/22/24

104

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



## Question Time

- Subscales of the Mother Scale  
(Equal Tempered Chromatic  
12 Note Scale)
  - Pentonic
  - Heptatonic (Diatonic)
- Modes
- Keys
- Tonics



- Zoomland
- In Person





# Course Outline



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