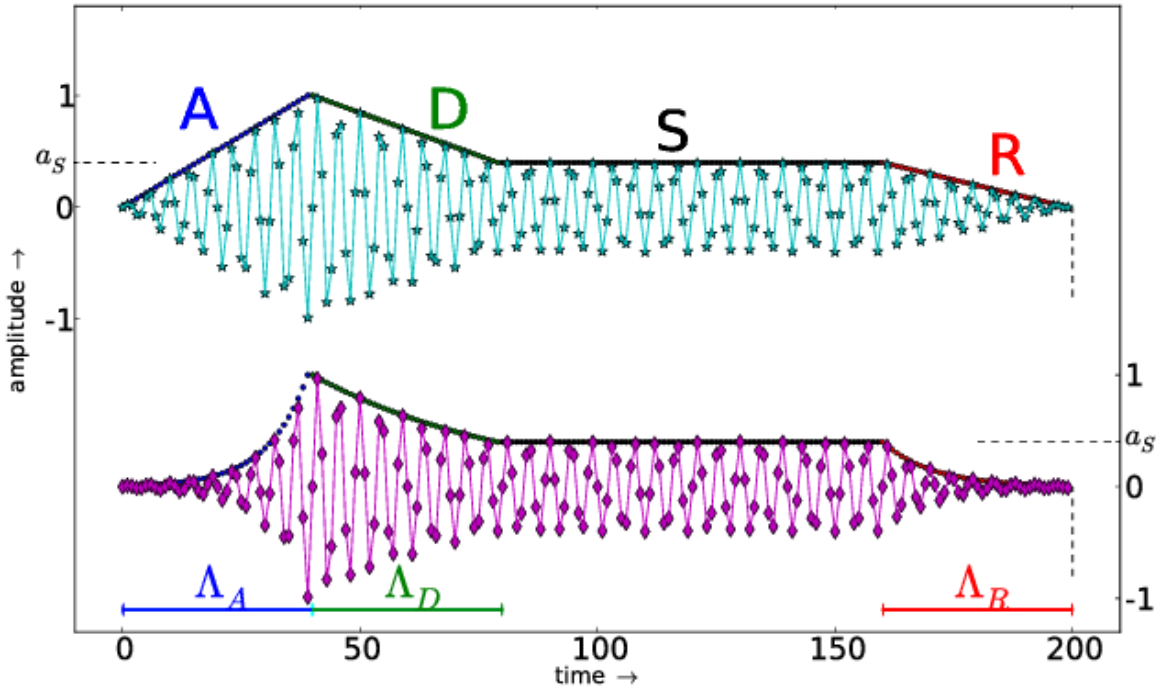
# Physics 1240: Sound and Music

**Today (7/22/19):** Fourier Synthesis, Sound Envelopes
***HW 2 due at the front of class, Homelab 2 due Wednesday*

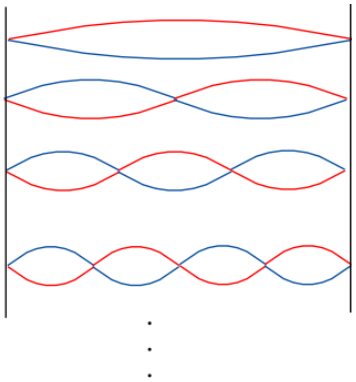
**Next time**: Midterm Exam



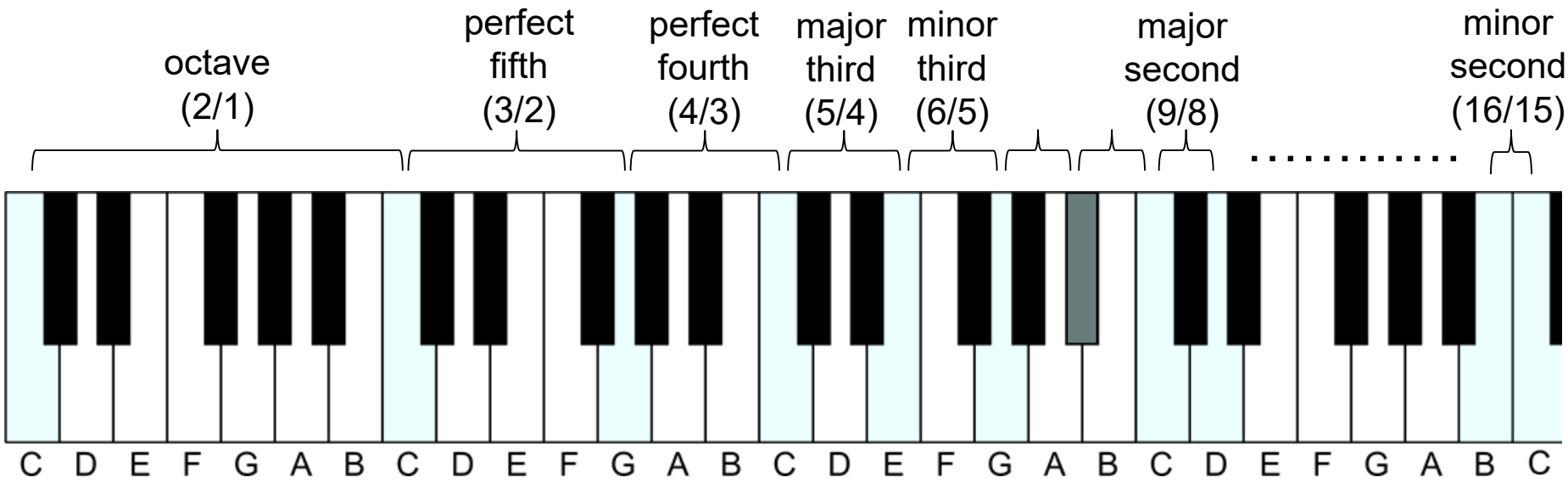
# Today's Agenda

- Announcements, Review (11:00-11:10)
- Discuss Fourier Synthesis/Sound Envelopes (11:10-11:50)
- Tutorial 6: review for midterm (11:50-12:20)
- Wine glass demo (12:20-12:35)

# Review



- Harmonic series: $f,\ 2f,\ 3f,\ 4f,\ 5f,\ 6f,\ \ldots$
- Tuning system: assigning a frequency to each note in a scale
- Temperament: tuning system that slightly compromises ("tempers") pure, harmonic intervals



# Review

- Just Tuning: uses only pure, harmonic intervals
  - Pros: all pure consonances for intervals from same note
  - Cons: can only play in one key
- Pythagorean Tuning: makes all fifths in any key pure (3/2)
  - Pros: all pure consonances for fifths
  - Cons: thirds are dissonant; Pythagorean comma
- Equal Temperament: same interval for all adjacent notes
  - Pros: can play in any key
  - Cons: all intervals are very slightly dissonant

| | Note name: | C | D | E | F | G | A | B | C |
|---|---|---|---|---|---|---|---|---|---|
| Just | Frequency ratio to C: | $\frac{1}{1}$ | $\frac{9}{8}$ | $\frac{5}{4}$ | $\frac{4}{3}$ | $\frac{3}{2}$ | $\frac{5}{3}$ | $\frac{15}{8}$ | $\frac{2}{1}$ |
| Pythagorean | | $\frac{1}{1}$ | $\frac{9}{8}$ | $\frac{81}{64}$ | $\frac{4}{3}$ | $\frac{3}{2}$ | $\frac{27}{16}$ | $\frac{243}{128}$ | $\frac{2.03?}{1}$ |
| Equal-Tempered | | $\frac{1}{1}$ | $\left(2^{\frac{1}{12}}\right)^2$ | $\left(2^{\frac{1}{12}}\right)^4$ | $\left(2^{\frac{1}{12}}\right)^5$ | $\left(2^{\frac{1}{12}}\right)^7$ | $\left(2^{\frac{1}{12}}\right)^9$ | $\left(2^{\frac{1}{12}}\right)^{11}$ | $\frac{2}{1}$ |

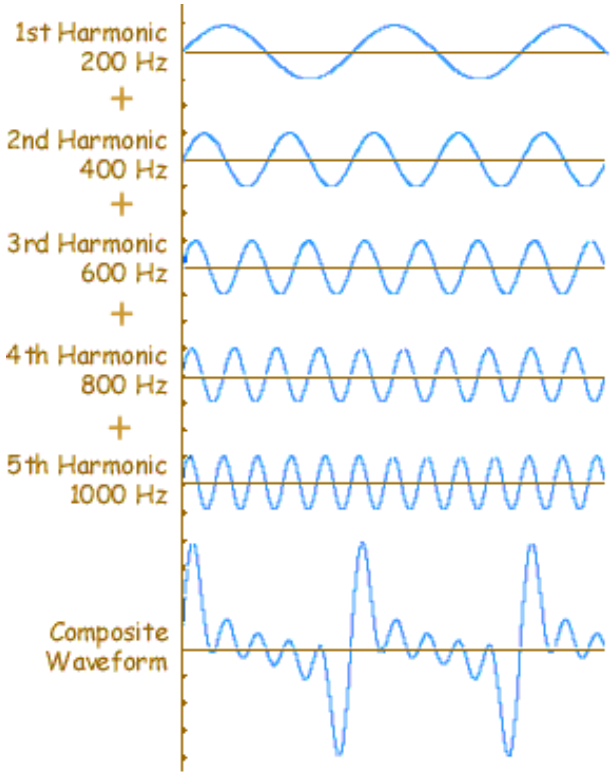
# Review

- Musical systems can have an arbitrary number of notes within one octave. Must balance:
  - Minimizing dissonance (more notes means more beats)
  - Increasing complexity (fewer notes means less interesting)

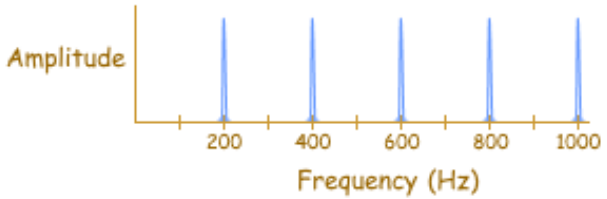
- Pentatonic (e.g. minor blues scale, Javanese gamelan)
- Microtonal

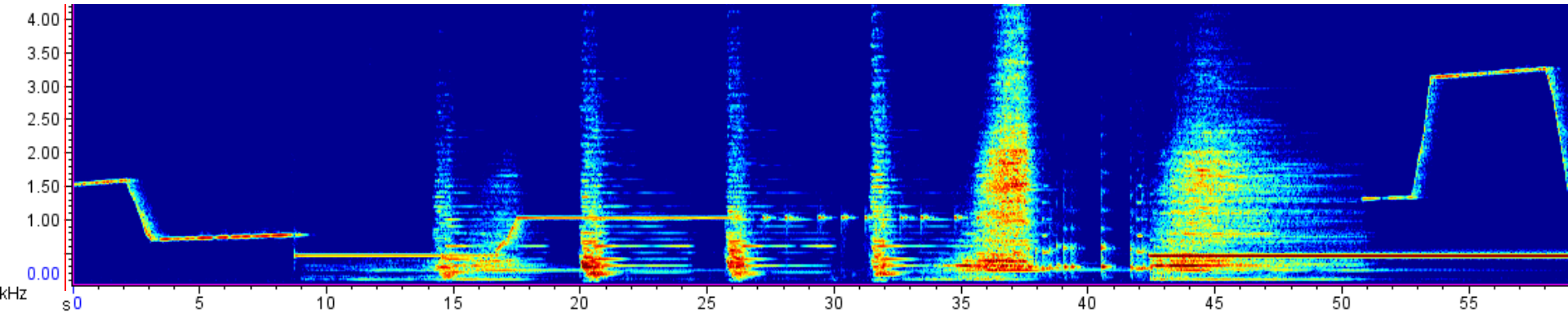
# Fourier Synthesis

- Fourier's Theorem: every **periodic** sound can be written as the sum of sine waves with **integer multiples of frequency**

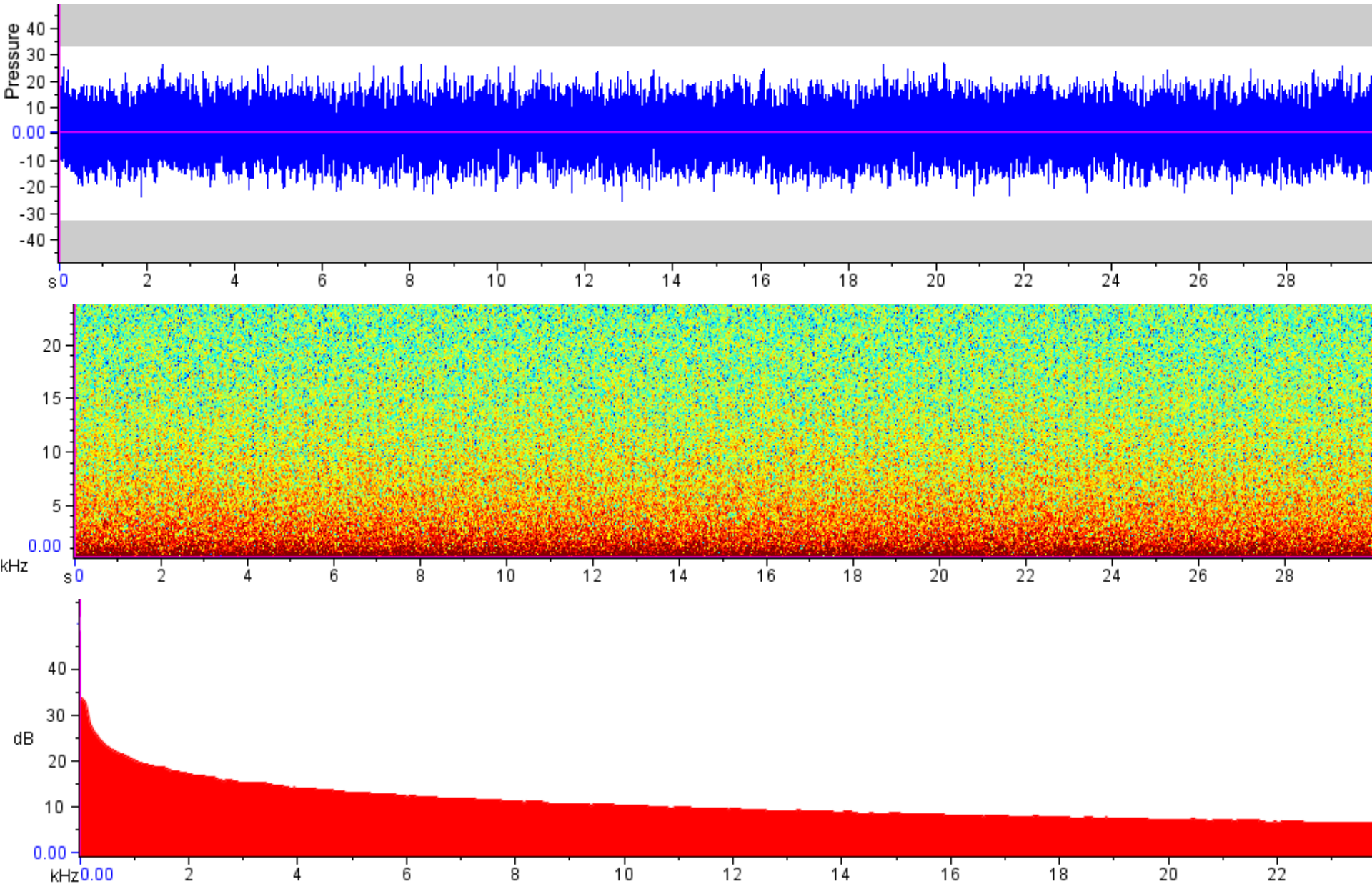



- *Noise*: waveforms have no periodicity, inharmonic spectrum
- *Tones*: periodic waveforms, harmonic spectrum



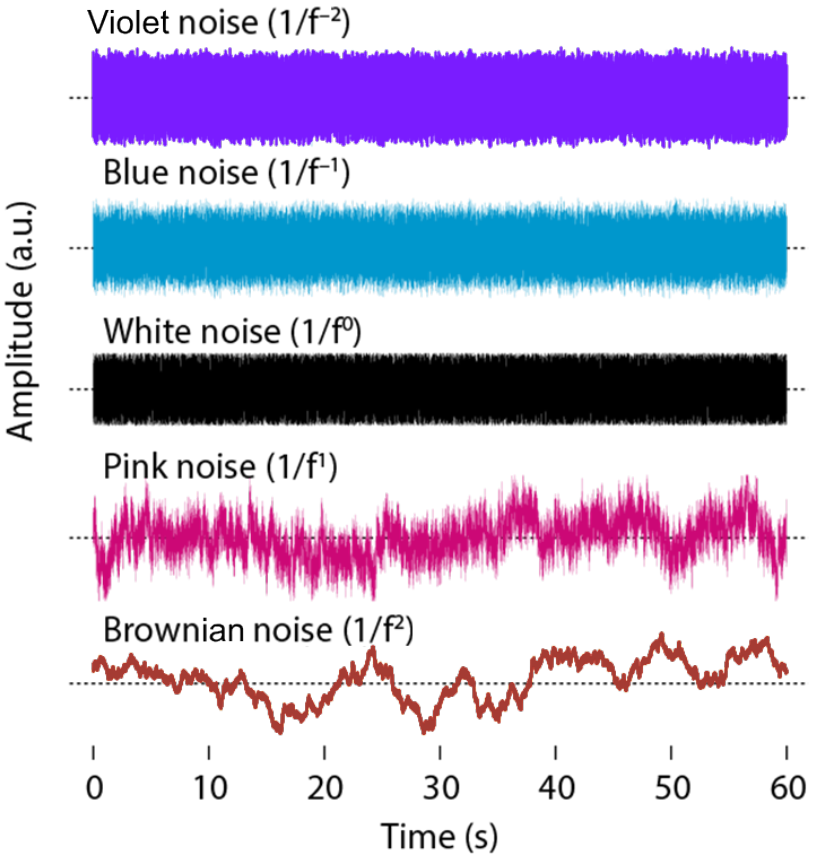

4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.00
kHz
s 0
5
10
15
20
25
30
35
40
45
50
55

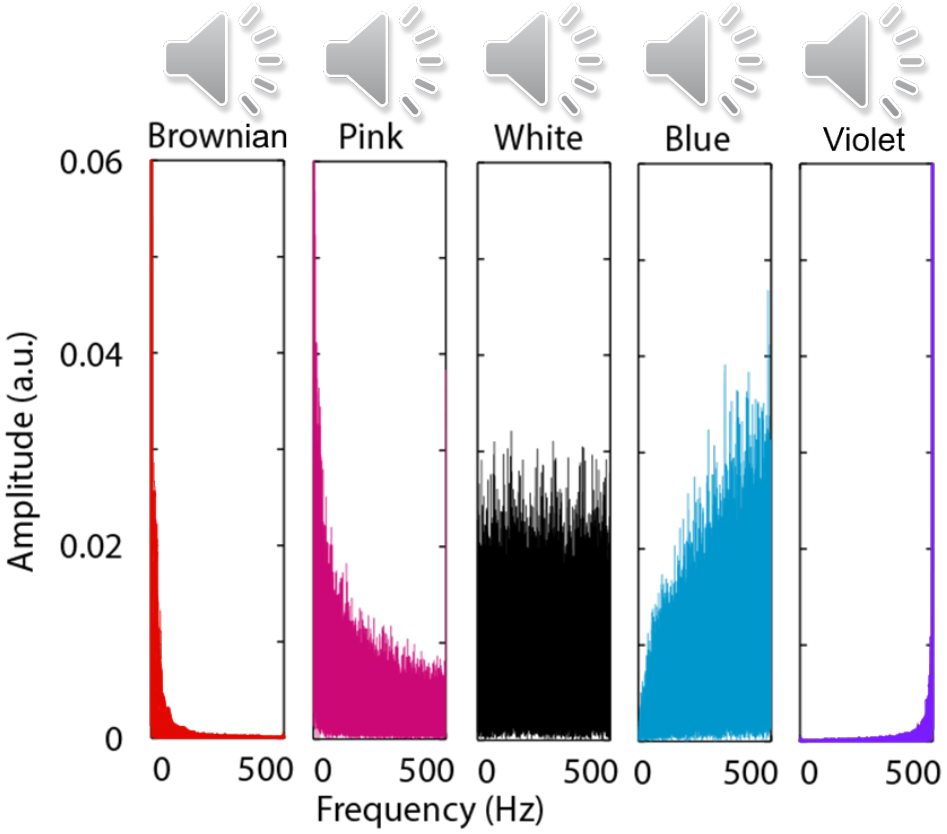
# Ways to represent sound



# Types of Noise

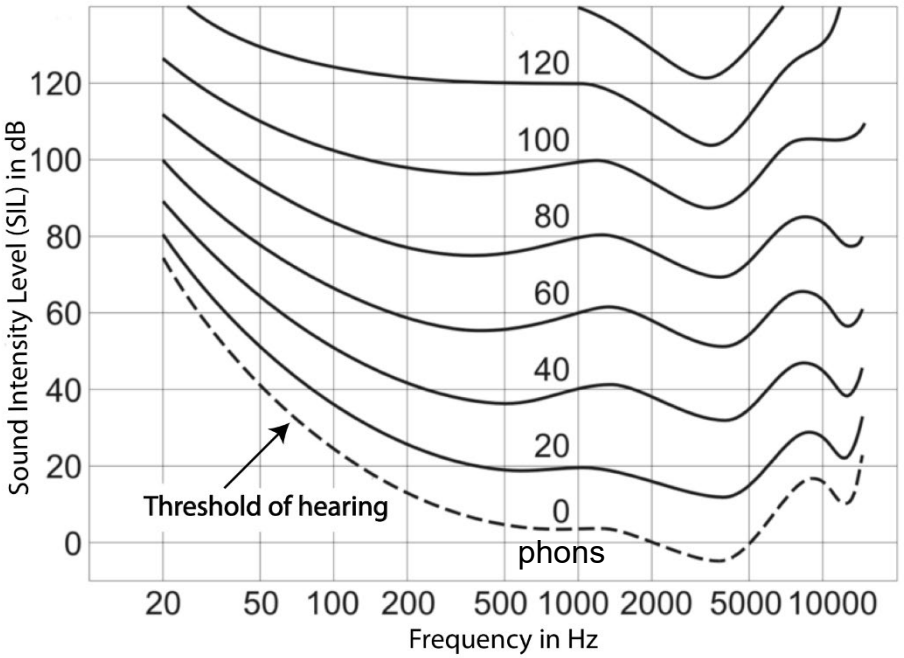
- White: flat spectrum; cymbals/snare/“sh”, acoustics EQ test
- Pink: equal energy per octave, testing speakers, background
- Violet: acoustic thermal noise of water
- Brownian: random walk

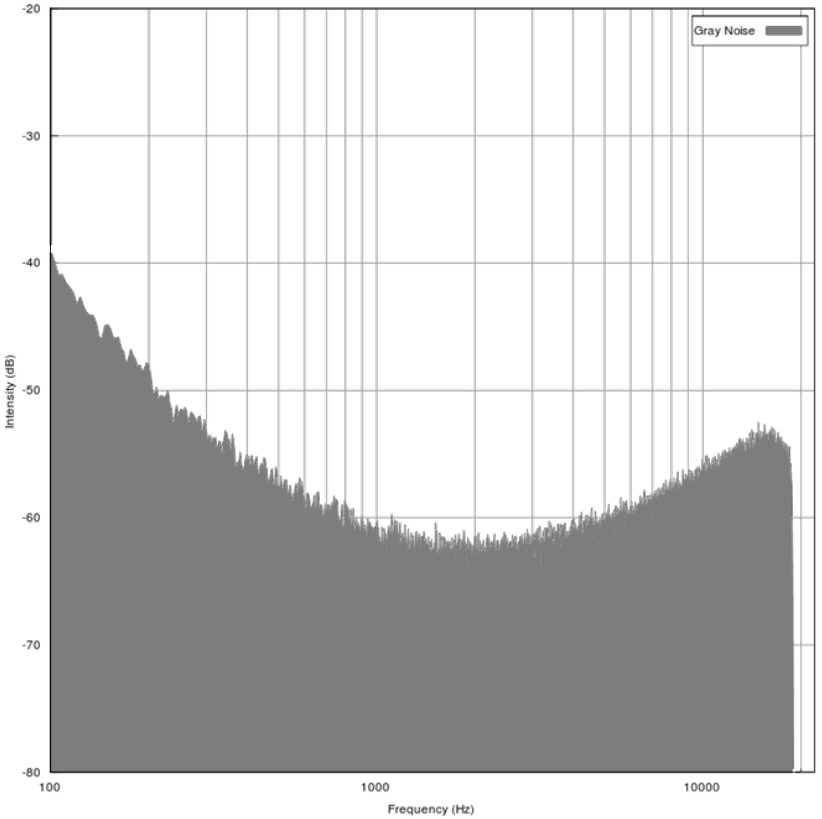



# Types of Noise (ctd.)

- Grey: equal loudness at all frequencies



## Clicker Question 10.1

How many of the following will produce random noise?

- A drummer playing at a steady 80 bpm (beats per minute)
- A toddler banging all the notes on a piano and screaming
- A phone's dialing sound
- A waterfall

A) 0
B) 1
C) 2
D) 3
E) 4

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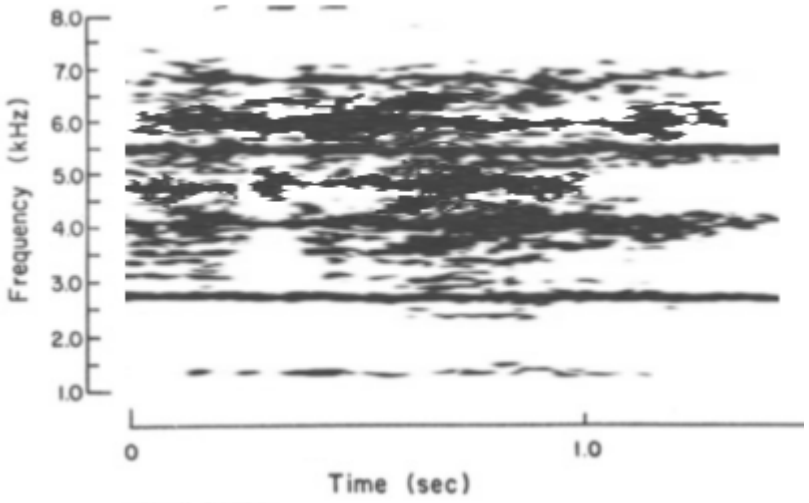
D) 3
E) 4

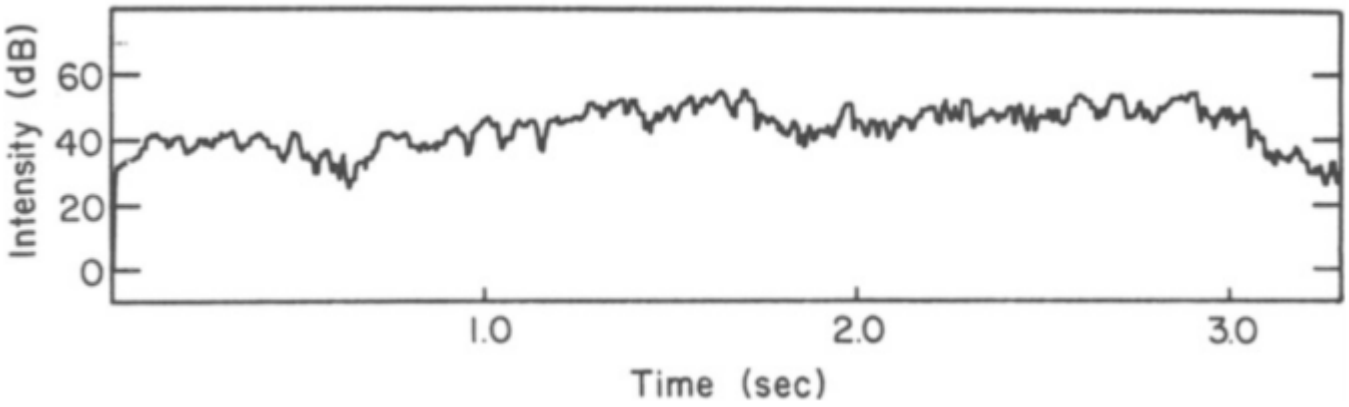
Drummer and waterfall
(piano and voice produce harmonic frequencies, no matter how cacophonous!)
(dialing sound: two pure tones)

## Clicker Question 10.2

What could the sound plotted below represent?

A) Violin playing a bowed note
B) Hitting a snare drum once
C) A plucked guitar string
D) Female voice singing
E) Fingernails scraping on a chalkboard



BA

https://improbable.com/ig/ig-pastwinners.html#ig2006

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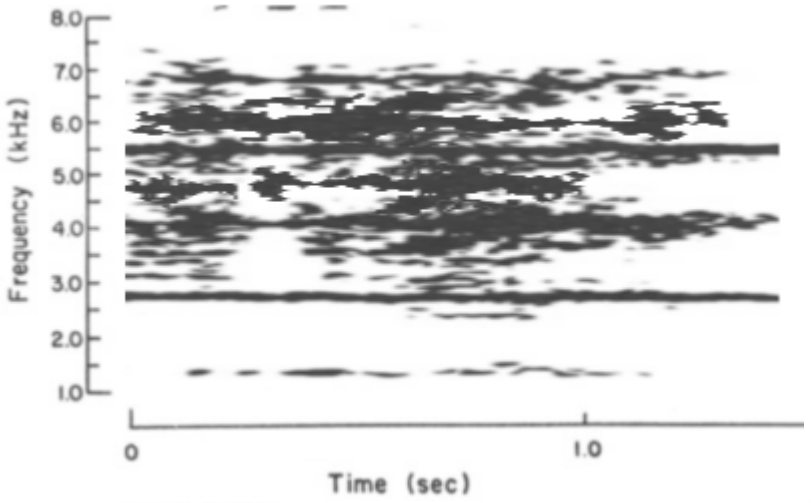
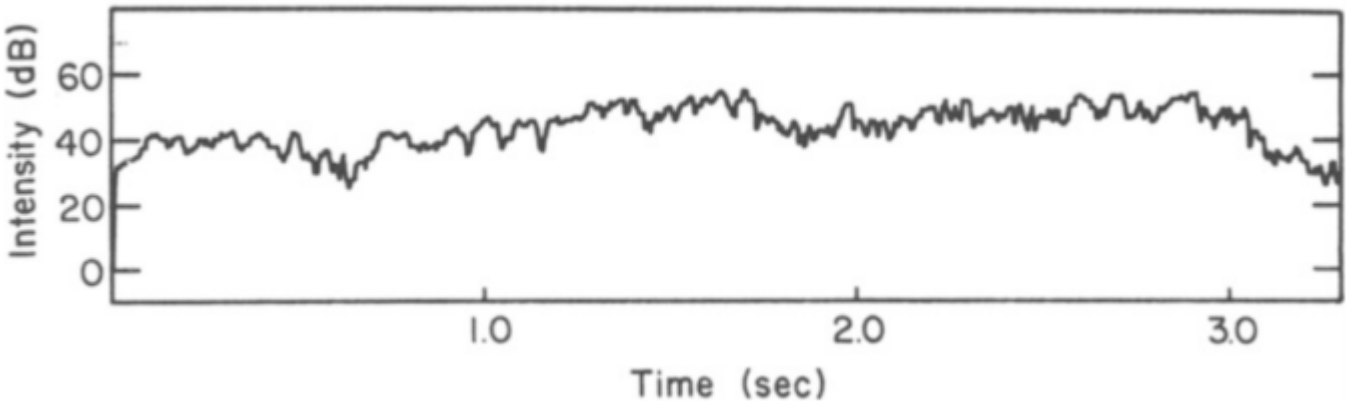
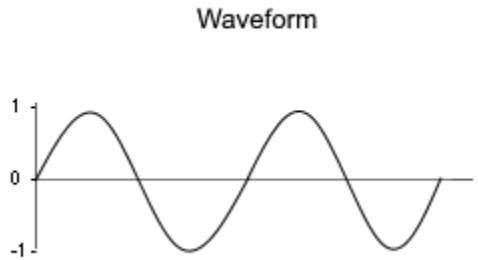


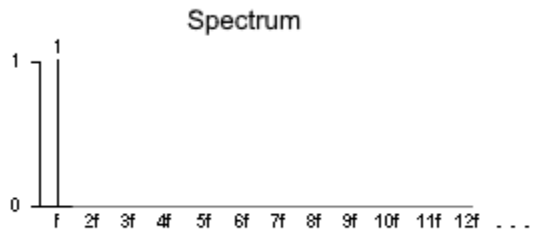



# Fourier Synthesis

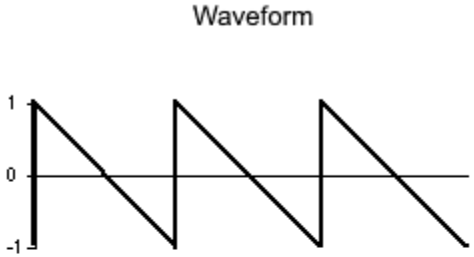
- Goal: recreate any periodic sound by combining harmonics with set amplitudes ("additive synthesis")
- Spectrum: list of relative amplitudes of harmonics present in a sound
- Simplest examples:

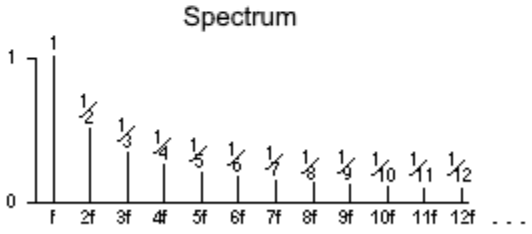
## Sine



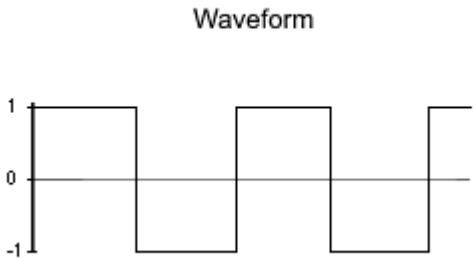



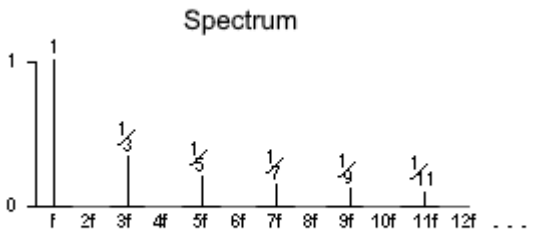

## Sawtooth




## Square



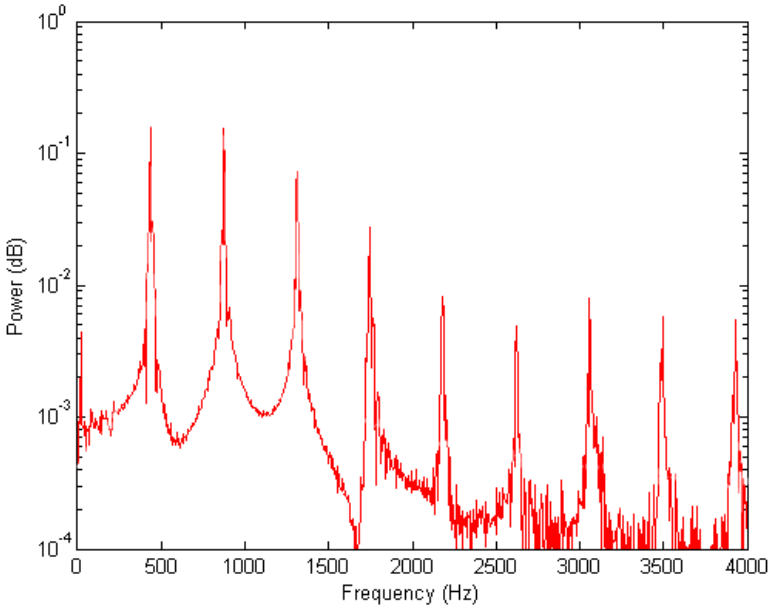
# Fourier Synthesis

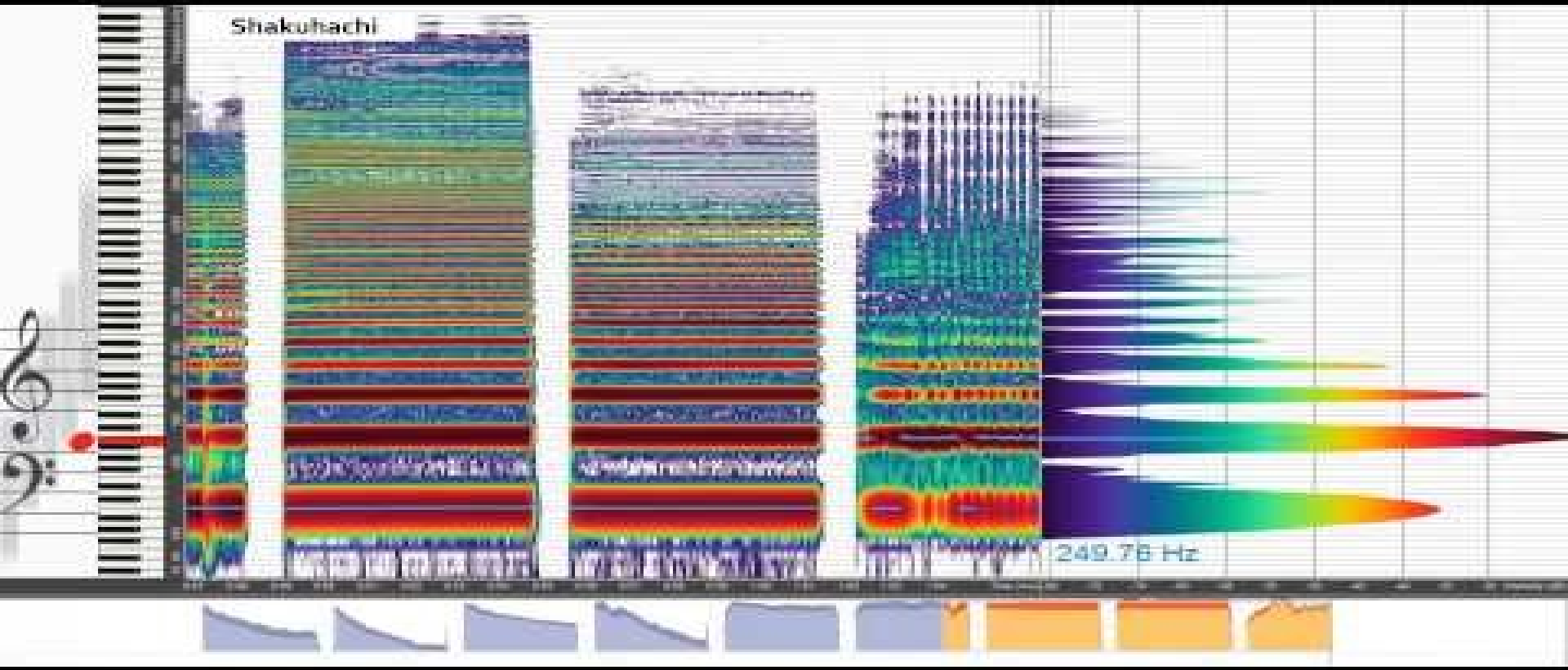
- Instruments: usually have harmonics *and* noise components

- Timbre can change on the same instrument playing different pitches or volumes

https://www.youtube.com/watch?v=VRAXK4QKJ1Q

Flute spectrum

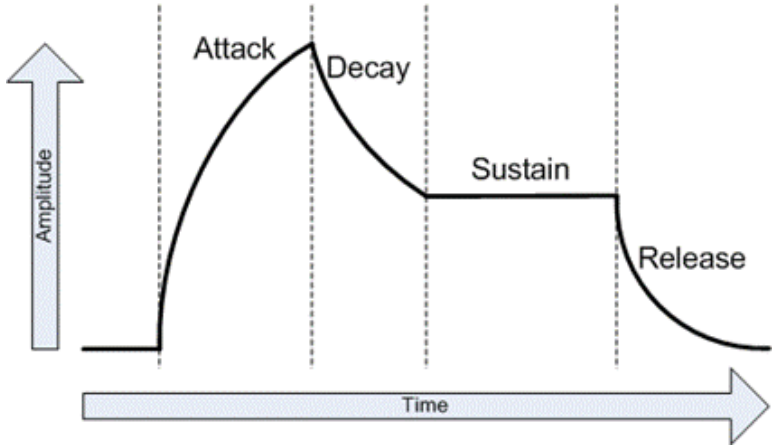



Shakuhachi
249.76 Hz

# Fourier Synthesis

- Need more than a spectrum to reproduce instrument sounds
  - e.g. middles of piano, cello, trumpet, triangle wave

- Sound envelope: graph of a sound's amplitude over the duration of a note
- ADSR:
  - Attack
  - Decay
  - Sustain
  - Release



# Fourier Synthesis

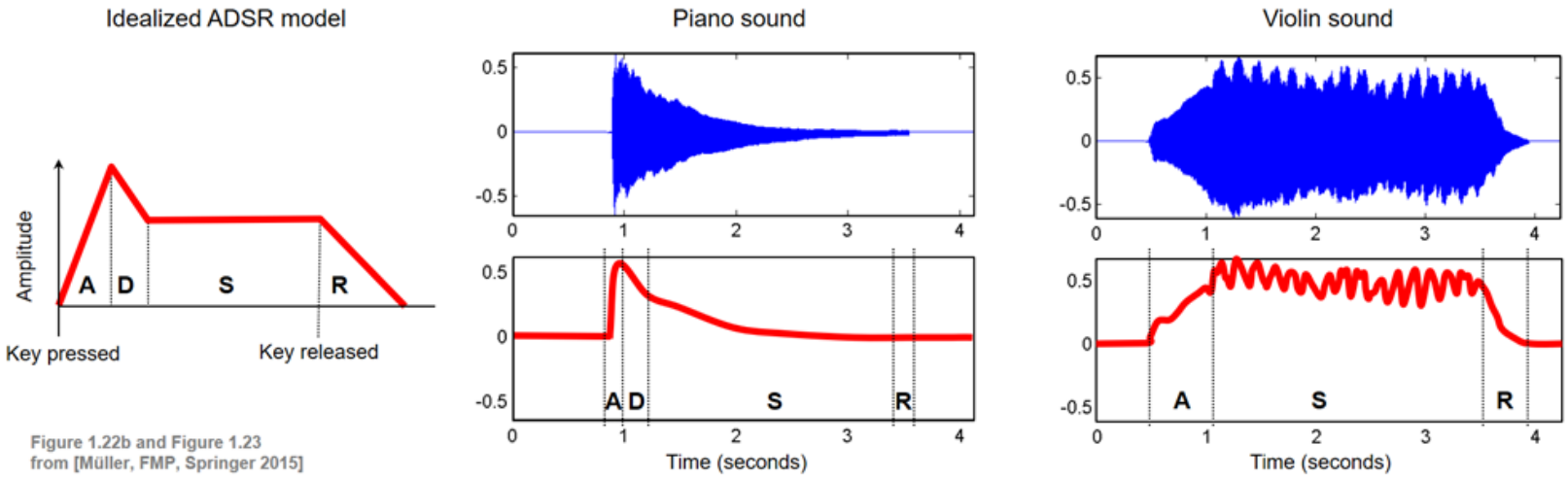



Figure 1.22b and Figure 1.23
from [Müller, FMP, Springer 2015]