PHY 103: The Physics of Music

Segev BenZvi
Department of Physics and Astronomy
University of Rochester

Structure of the Class

- We will have weekly lectures on Tuesdays. This week and next are special and will have Thursday lectures
- You will have weekly 2h 40m sessions in the Music Lab (B&L 403) starting in two weeks (Sep. 12)
  - Study topics in acoustics and instrument design
  - Write up a lab report based on your work
  - You will conduct ten labs in total during the semester
  - No make-up labs, but you are allowed to miss up to 2 labs given a valid excuse

Class Instructors

Segev BenZvi (Instructor)

sybenzvi@pas.rochester.edu

Office Hours (B&L 405):
Th 9:30 - 11:00

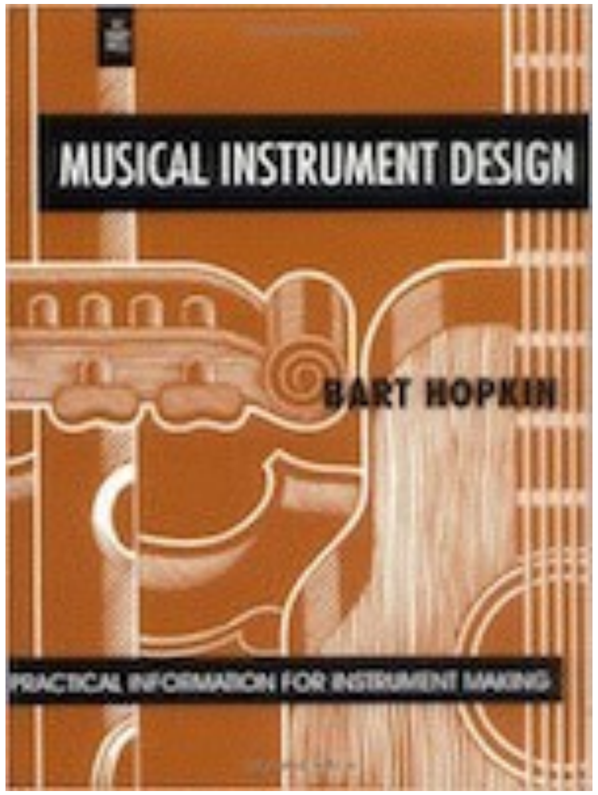
Luke Okerlund (TI)

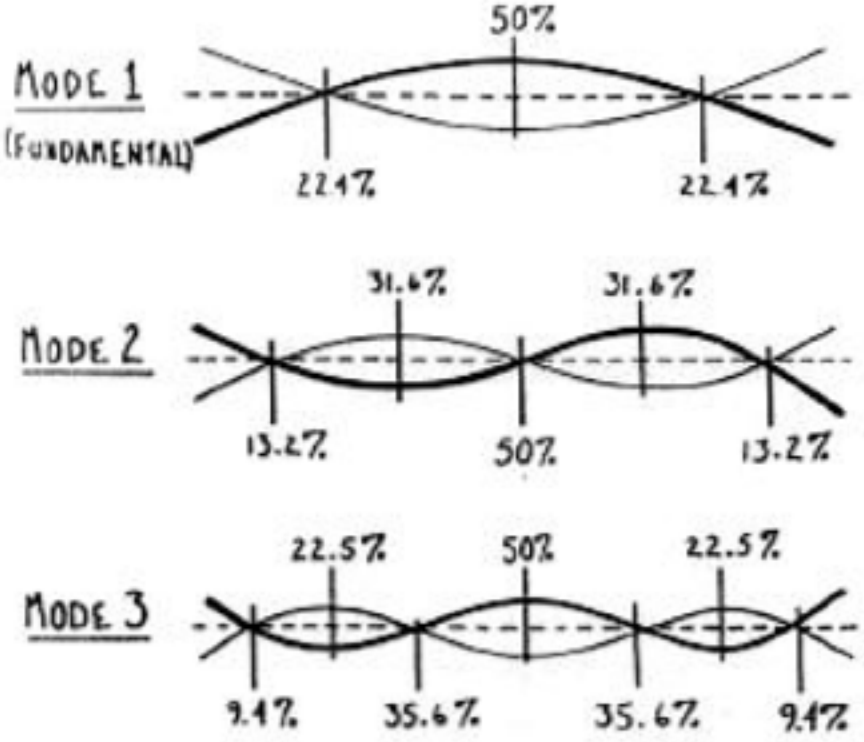
lokerlun@u.rochester.edu

We will help you in the lab and can answer questions about reports, but we are not available to you 24/7. Do not abuse our time!

Textbook

- The course text is *Musical Instrument Design* by Bart Hopkin





- A nice book with lots of great hand-drawn illustrations and practical advice about acoustics and instrument design
- The book can be dense and not very mathematical, so several other books are on reserve at POA (see Blackboard)

Grading

Lab Reports	**60%**
Class Participation	10%
Midterm	10%
Final Project	20%

- Lab manual: will be distributed next week
- Individual labs will also be posted to Blackboard in PDF files at the start of each week
- You will have one week to turn in your reports (reports must be handed in by 2 pm on Monday)

Building Instruments

- In this course you will be doing a lot of hands-on work in the Music Lab (B&L 403)
- The outcome of the class will be an instrument of your own design that you can take home with you
- The physical labor and craftsmanship can be incredibly satisfying in their own right, and I hope you have a lot of fun
- That being said…

A Note on Shop Safety

Working in the Lab

- Some tools you will use in the lab are shown below. They are all quite safe if used properly

Hot glue gun

Rotary cutter/grinder

Band Saw

Drill Press

Safety Policy

- Keep your eyes and *mind* on your task
- If you're not sure how to do something safely, ask for help
- DON'T RUSH
- Work with a partner
- If you see someone doing something unsafe, STOP THEM

If you disregard safety, you will be asked to leave the lab.

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- Midterm: mid to late October, largely conceptual
- For the final project you will build an instrument and play it for the class
- The "performance" will be short (10-15 minutes) and is meant to be fun. You will be graded on your work and your understanding of the concepts in the course, not your musicianship

Course Topics

- Physics
  - Propagation of sound waves
  - Normal modes and resonance
  - Acoustics of musical instruments
  - Musical scales and temperament
  - Harmonic analysis and timbre
- Psychoacoustics
  - The perception of music and sound

Psychoacoustics

- We have both physiological and psychological responses to sound:
  - Physiological: our hearing system is pretty amazing. We perceive sound waves across a large range in frequency and loudness
  - The sound is converted to electrical impulses by the nerves in our ears
  - Psychological: our interpretation of these nerve impulses. The brain takes a lot of shortcuts, and our hearing system can be fooled ("auditory illusions")

Memory Association

- When you hear this clip, you may think of a pop song

play

- When I hear it, I think of this:

(c) 1966, CBS, Universal Studios

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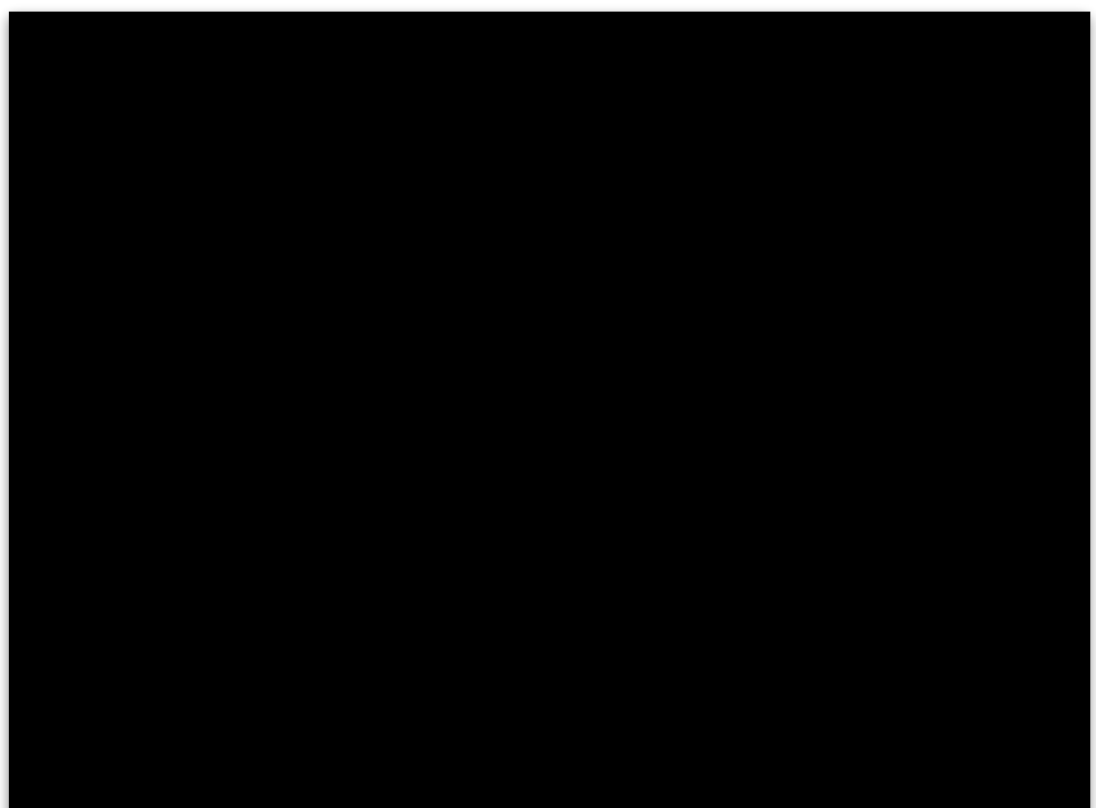

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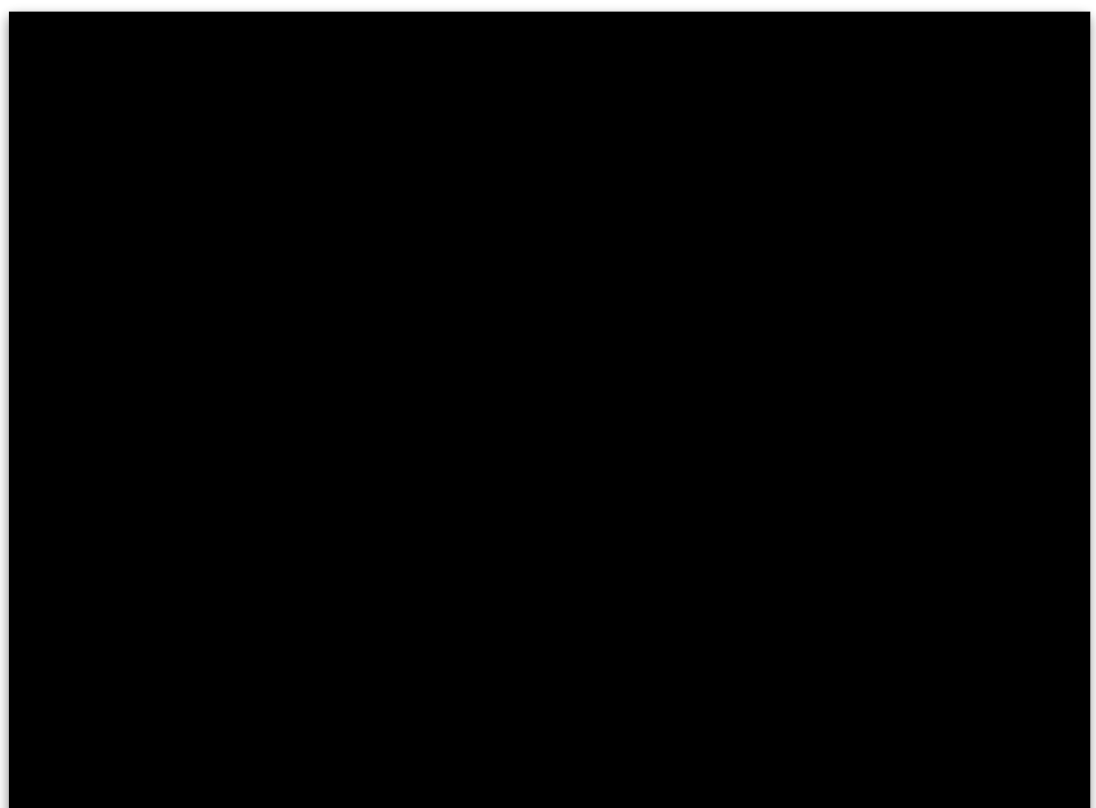

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Emotional Response

- *Frisson*: the shivering "goosebump" feeling you may get when listening to certain pieces of music
- Autonomous Sensory Meridian Response (ASMR), a more intense goosebump/bubbly feeling
  - Colloquially known as a "braingasm" (I'm not making this up). Linked to *synesthesia*?
  - Controversial, not widely accepted as a real effect
- Misophonia: "hatred of sound," e.g., chewing, slurping, scraping, etc., which gives rise to a combination of anxiety, anger, and disgust

Example: Screams

- Scream 1 (male. Recognize it?)

  play

- Scream 2 (female)

  play

- Scream 3 (female)

  play

- How do you respond to these sounds? Are they funny? Intense, or upsetting? Why?

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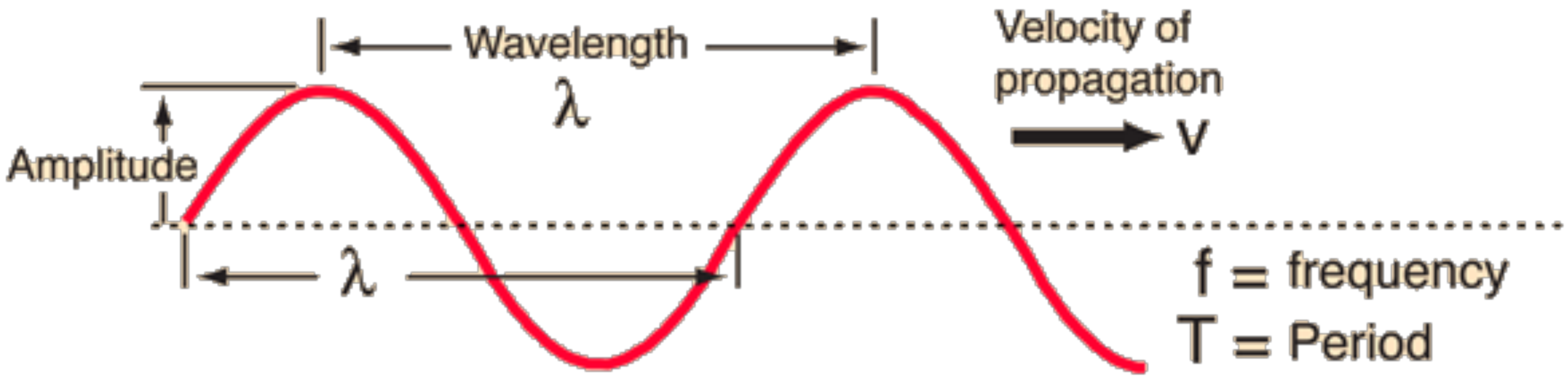
On to Physics…

- Sound is a wave phenomenon, so let's spend the rest of this class reviewing the basics of waves

Properties of Waves



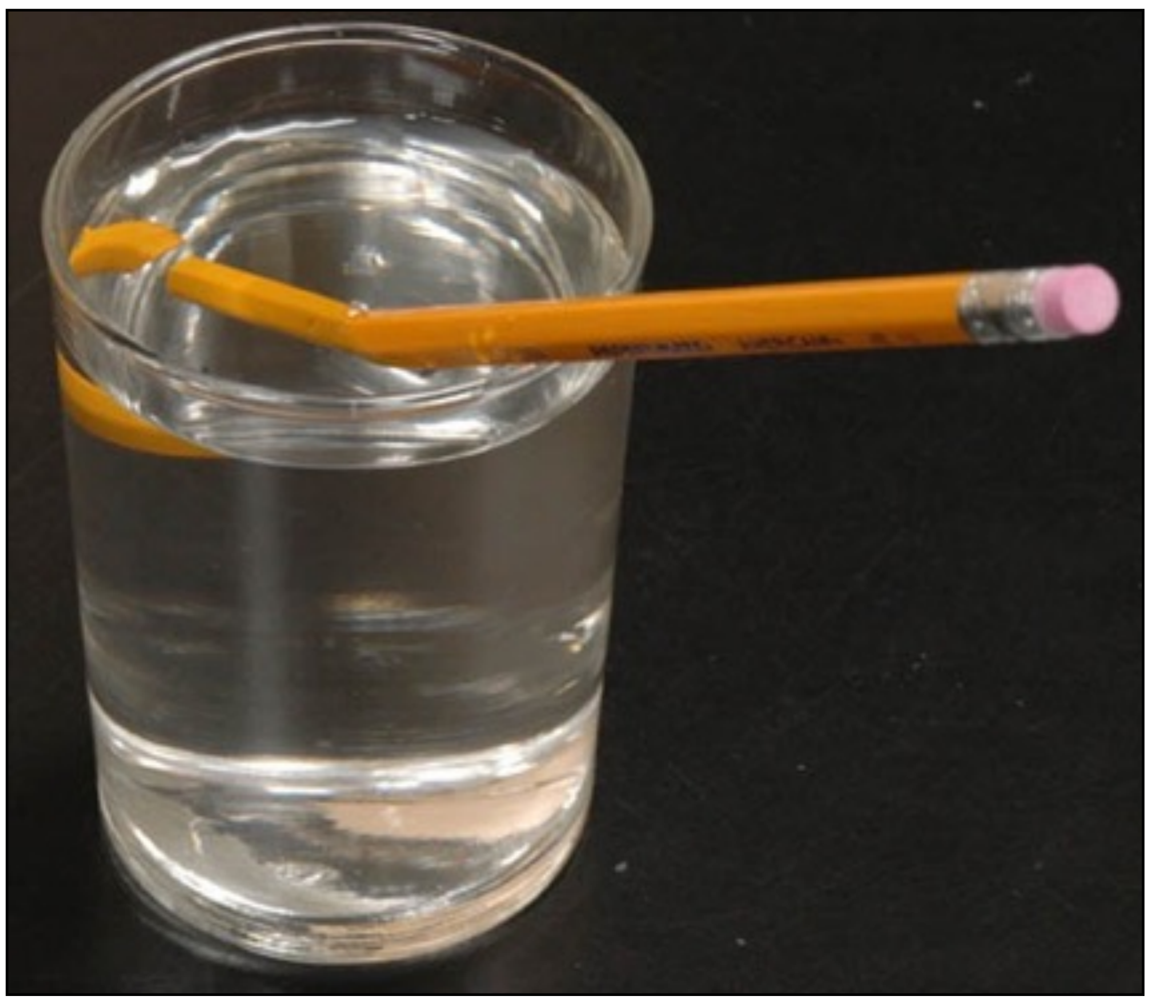
- Wavelength: λ, length to repeat peak-peak (trough-trough)
- Period: τ, time to repeat one cycle of the wave (seconds)
- Phase: position within the wave cycle (a.k.a. *phase shift* or *offset*)
- Frequency: $f = 1/\tau$, units of Hertz (1/second)
- Amplitude: A, distance from oscillation midpoint to peak
- Velocity: $v = f\lambda = \lambda/\tau$
- Energy: $E \sim (\text{Amplitude})^2$

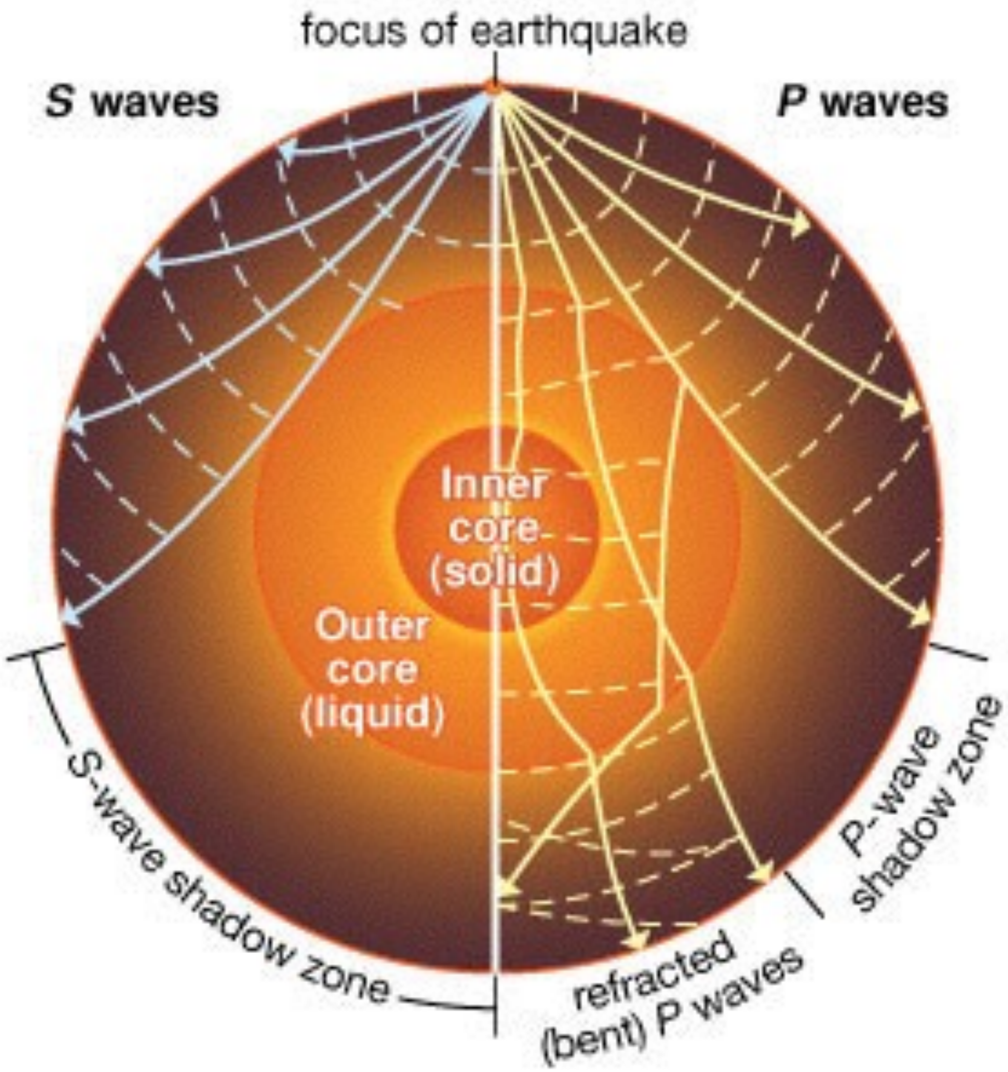
Behavior of Waves

- Behavior typical of waves:
  - Reflection: when a wave strikes a surface and bounces off
  - Refraction: when a wave changes direction after passing between two media of different densities
  - Diffraction: the bending and spreading of waves around an obstacle, often creating an *interference* pattern
  - Polarization: the orientation of the oscillation of transverse waves
- How to tell if light is a wave: perform experiments on pulses of light and see if they exhibit these behaviors…

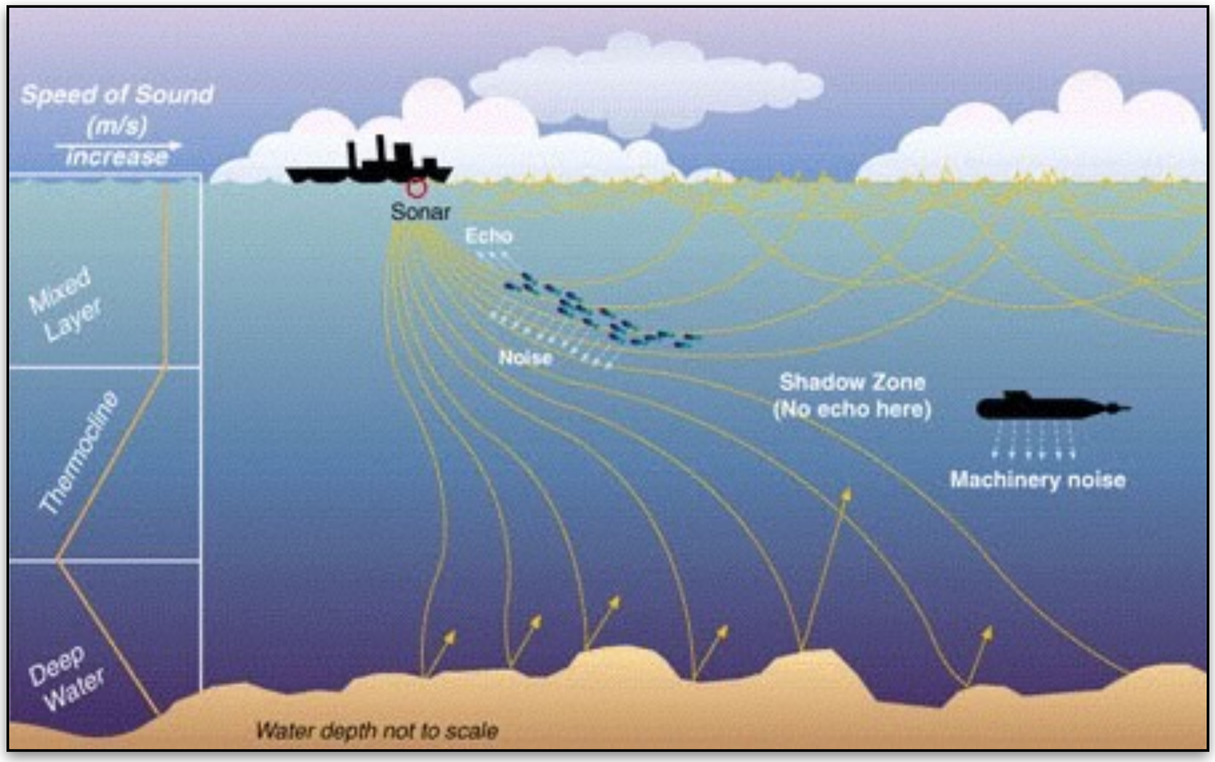
Refraction

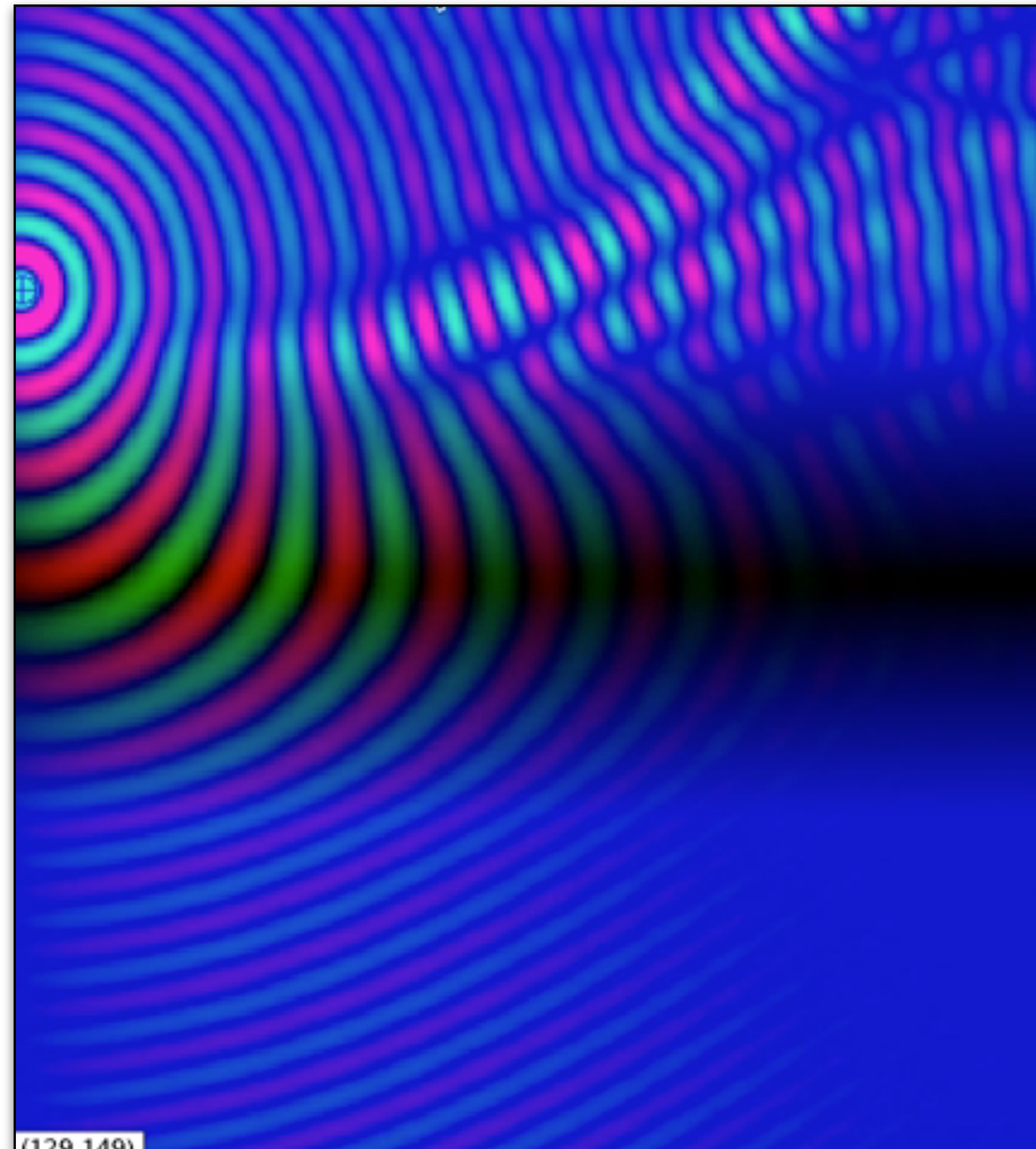
- When waves move from a medium of one density into a medium of a different density, their paths bend
- Electromagnetic refraction (left); acoustic refraction (right)





Refraction: Sonar





Ripple Tank: P. Falstad, www.falstad.com

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- Can create shadows for naval sonar

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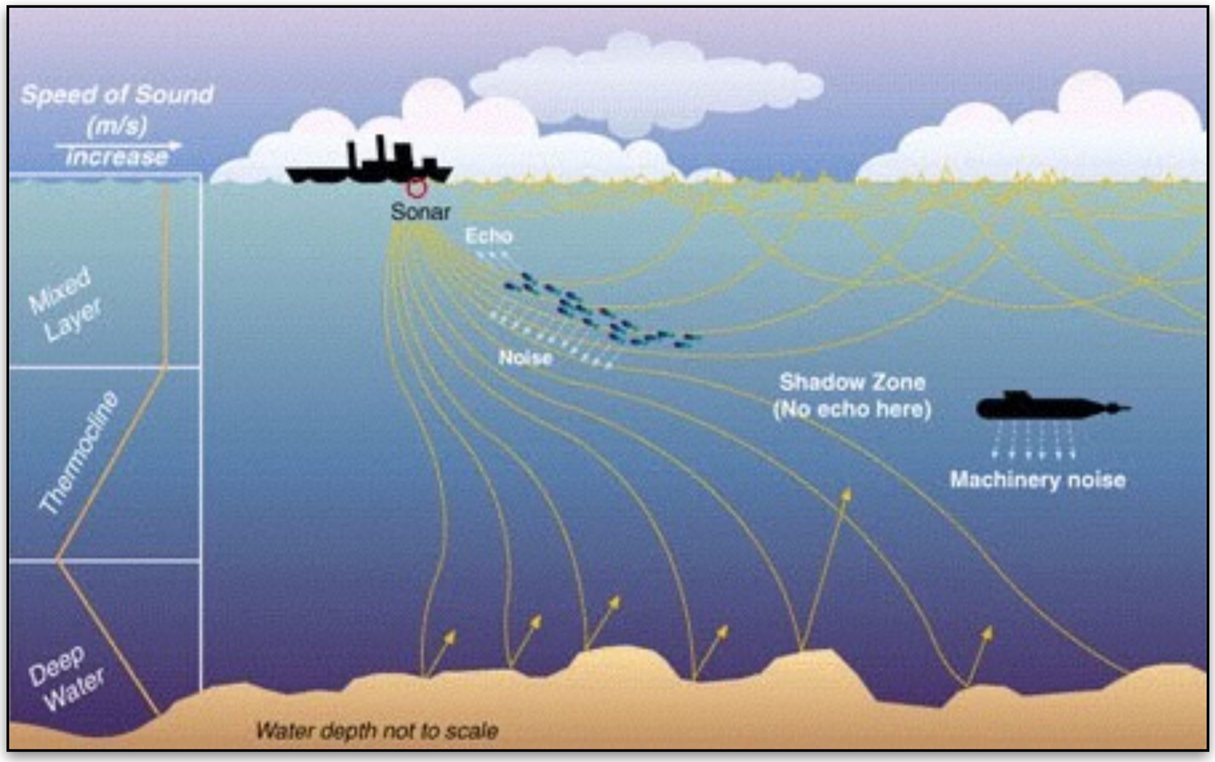

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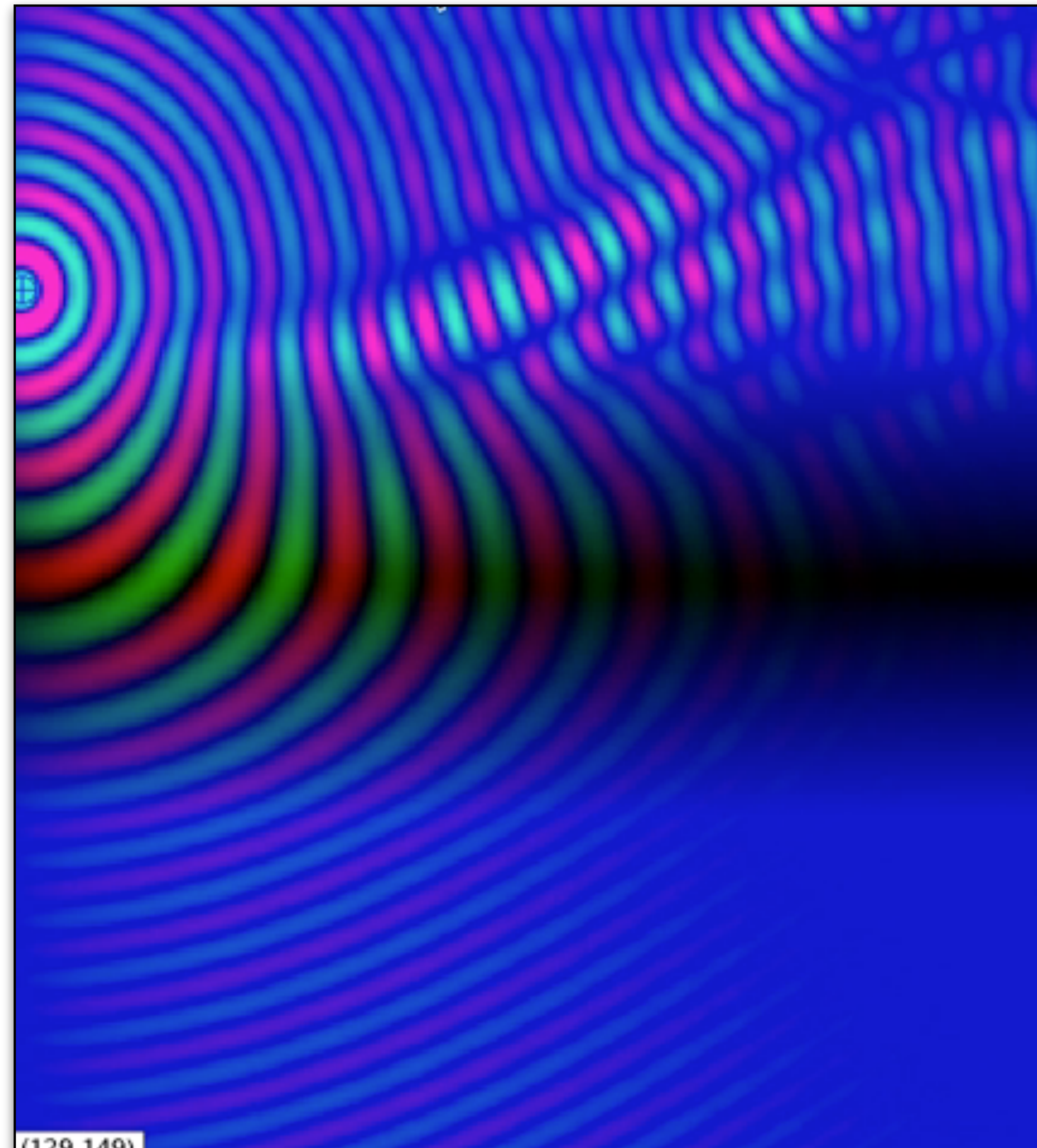

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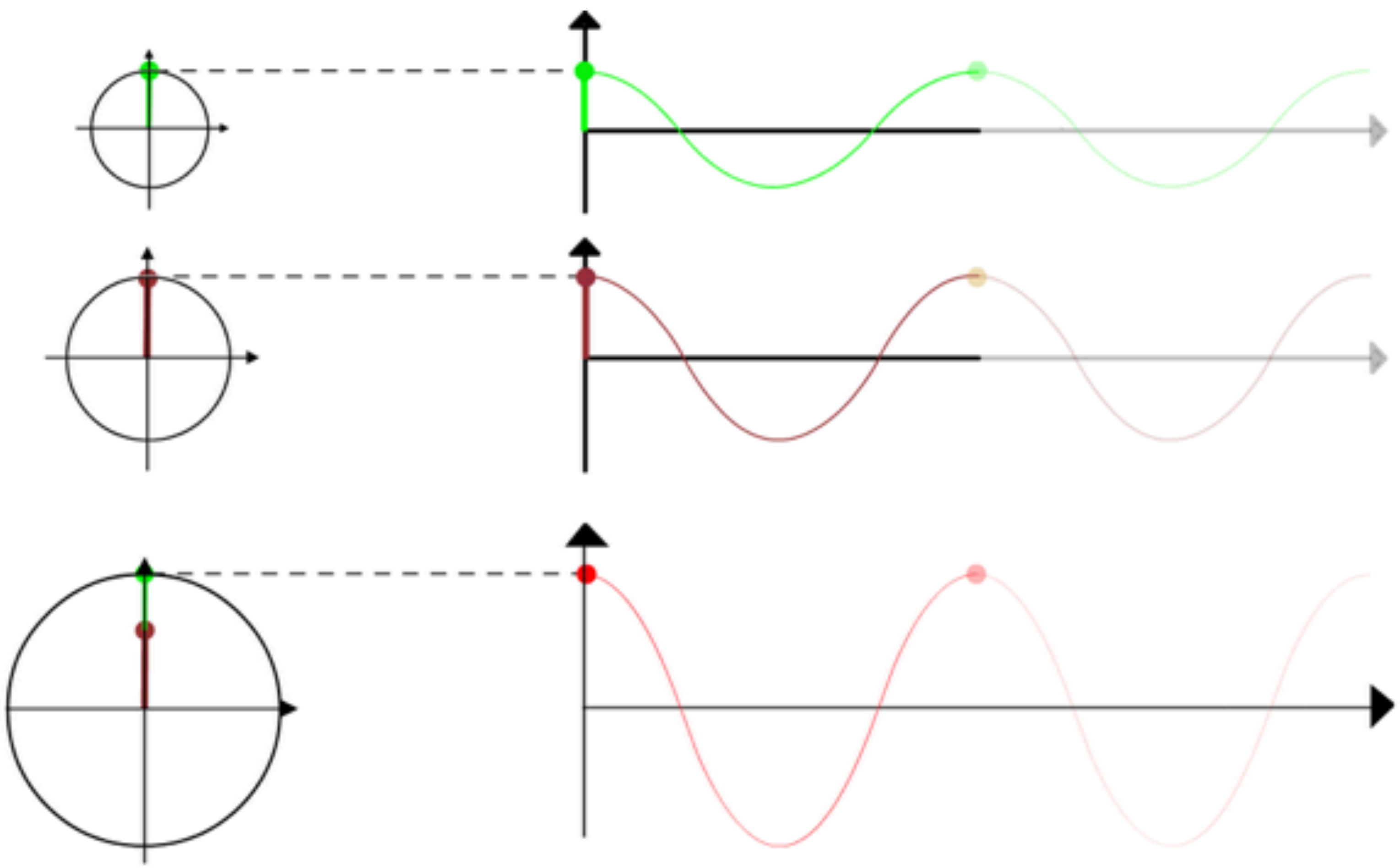
Interference

- Two waves can add to form a bigger wave



$$y_1(t) = A\sin(2\pi ft)$$

$$y_2(t) = B\sin(2\pi ft)$$

$$y(t) = y_1 + y_2 = (A+B)\sin(2\pi ft)$$

- This is known as constructive interference
- The waves are *in phase*: the peaks and troughs align

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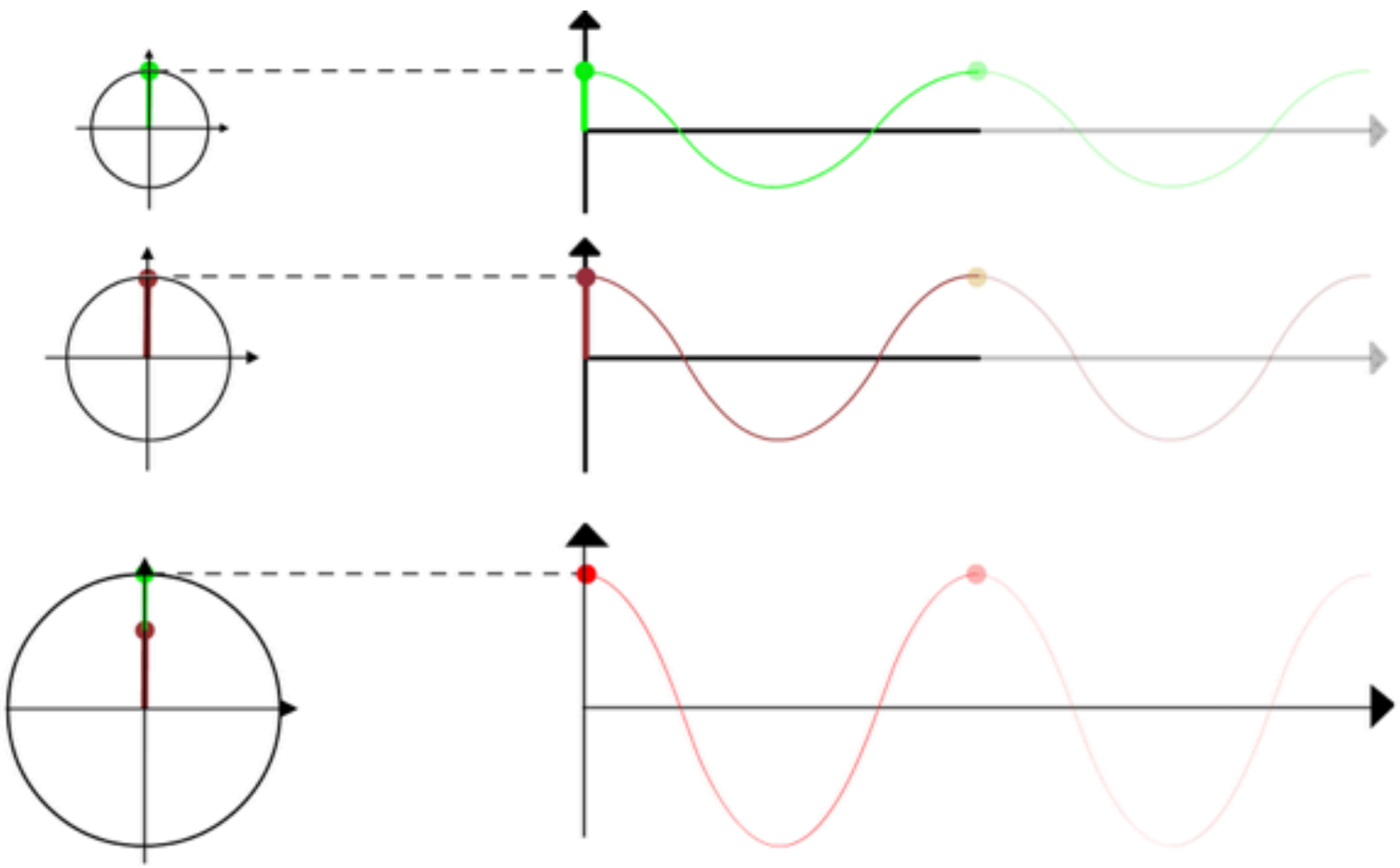

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Interference

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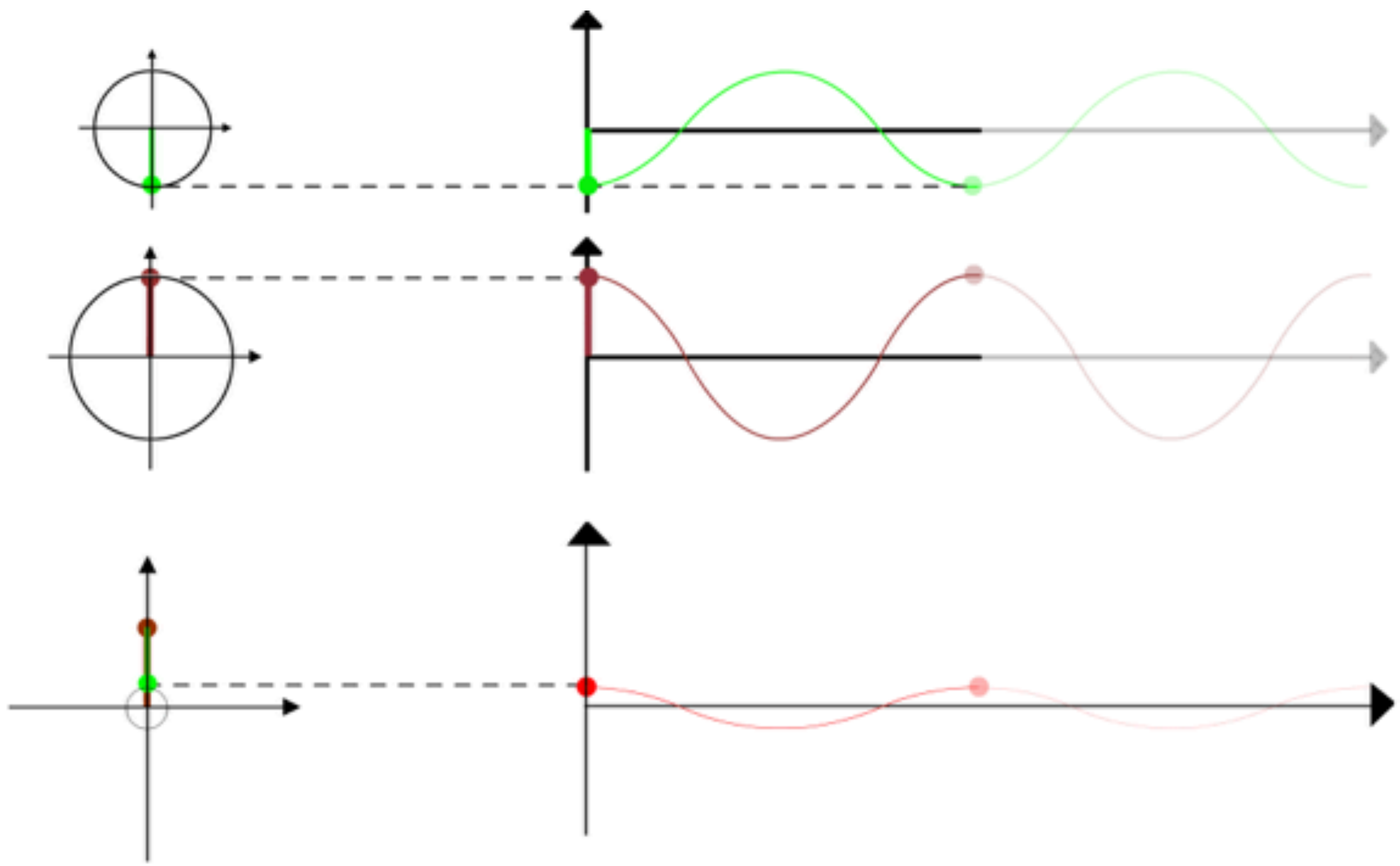

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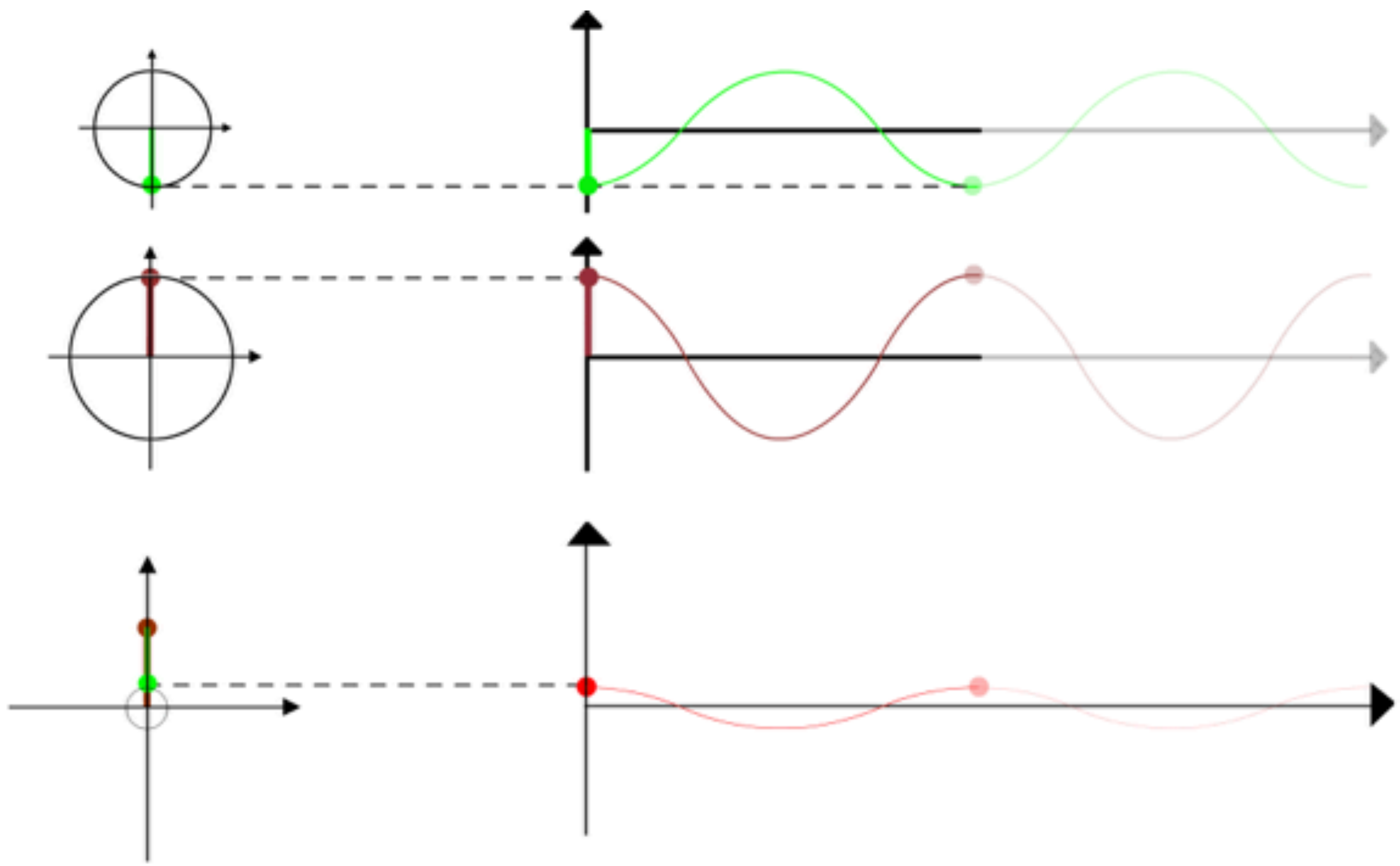

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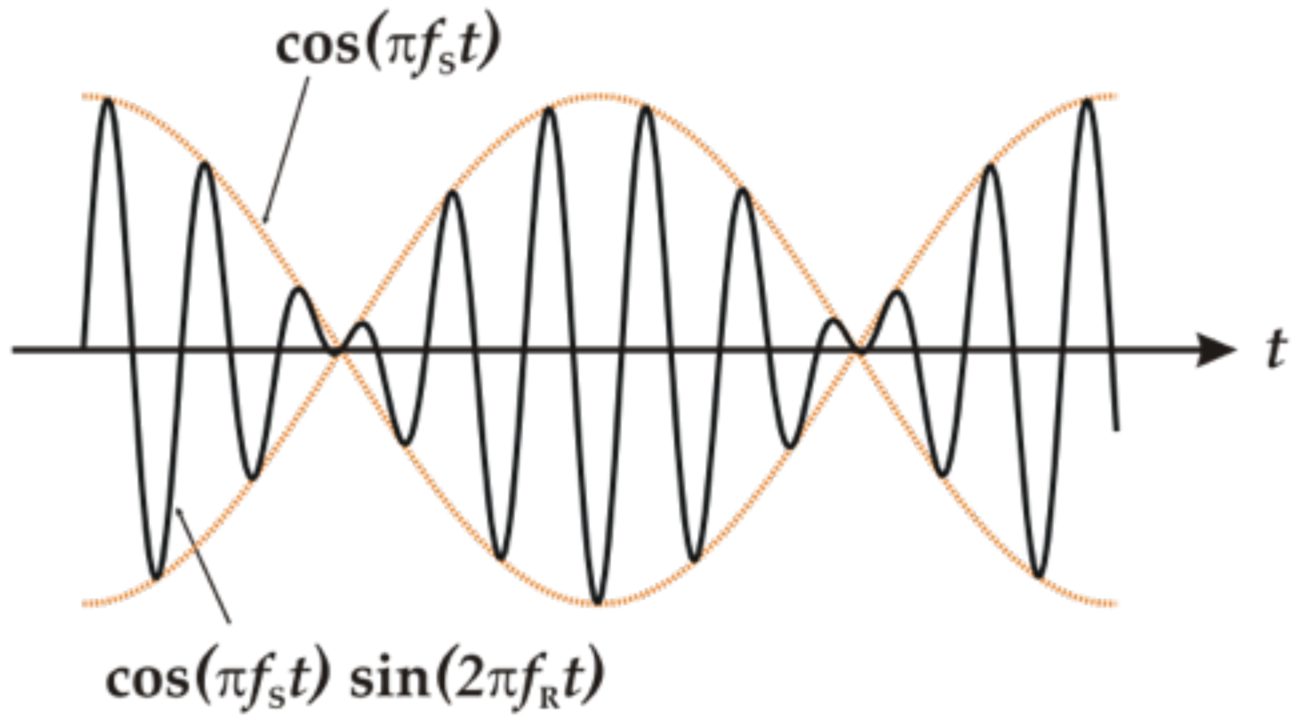
Interference

- So far we have considered addition of waveforms with equal frequency but different phase
- What happens when we add waves of slightly different frequencies?

Beats

- When two waves of different frequencies add, they move in and out of phase with respect to each other

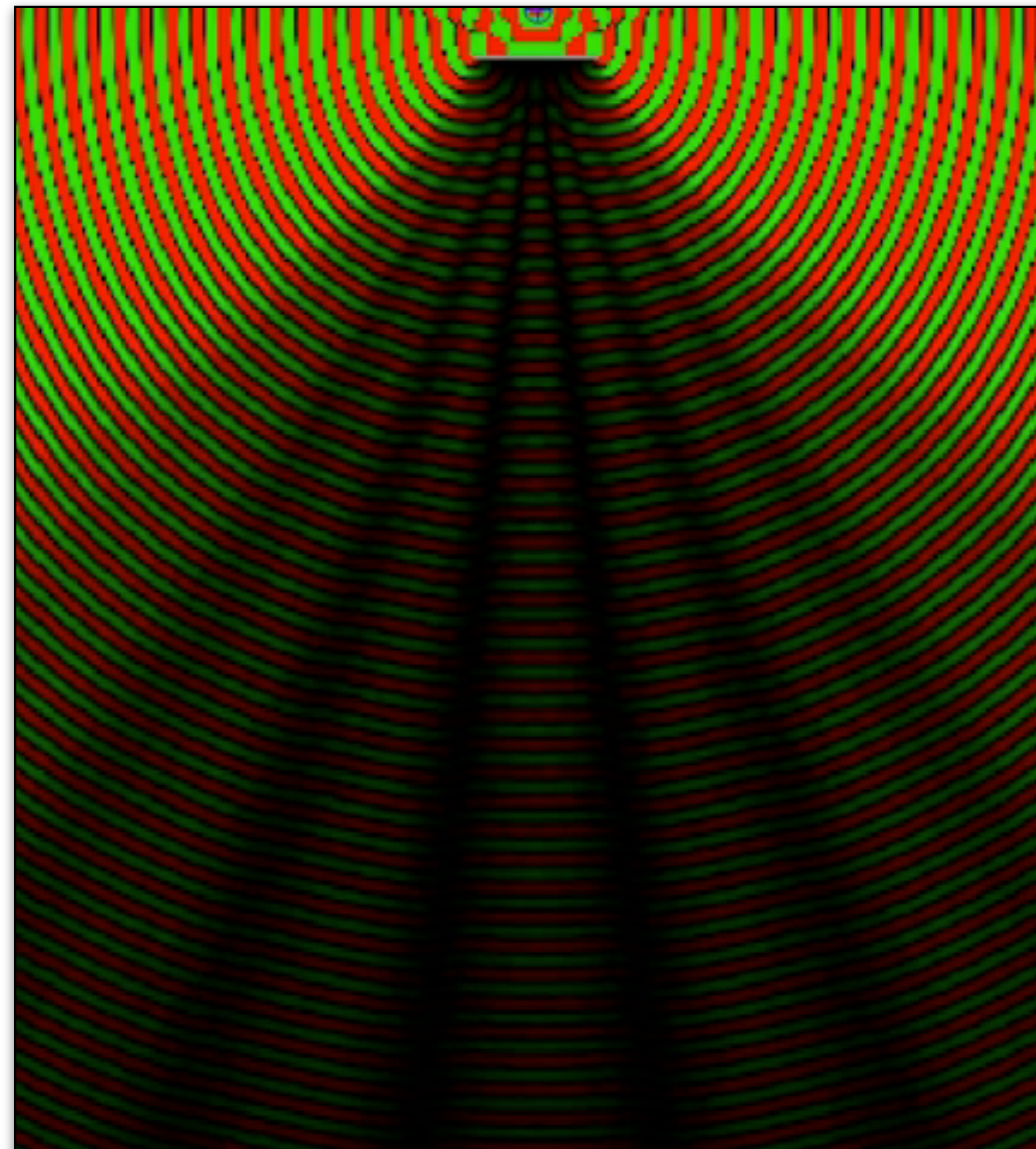


- When the frequency difference is <10 Hz, we can hear the differences as a "beating" of the envelope of the combined waveform

- Larger differences just sound like two tones

Diffraction Around a Barrier

- Waves can bend, or diffract, around a barrier
- This is why you can hear sounds from around a corner
- The interference from different parts of the wave can produce acoustic shadows with a distinct "fringe" pattern



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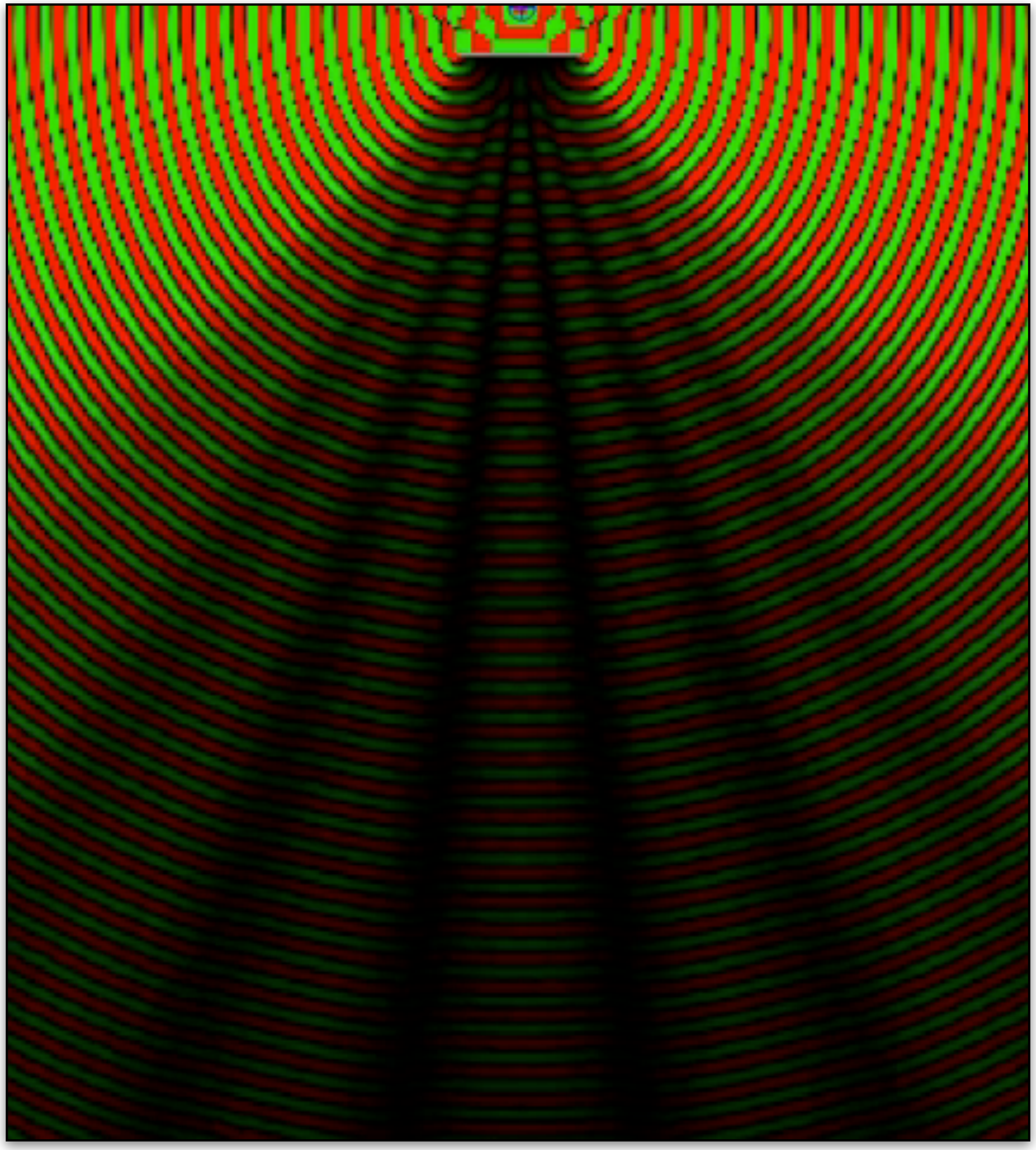

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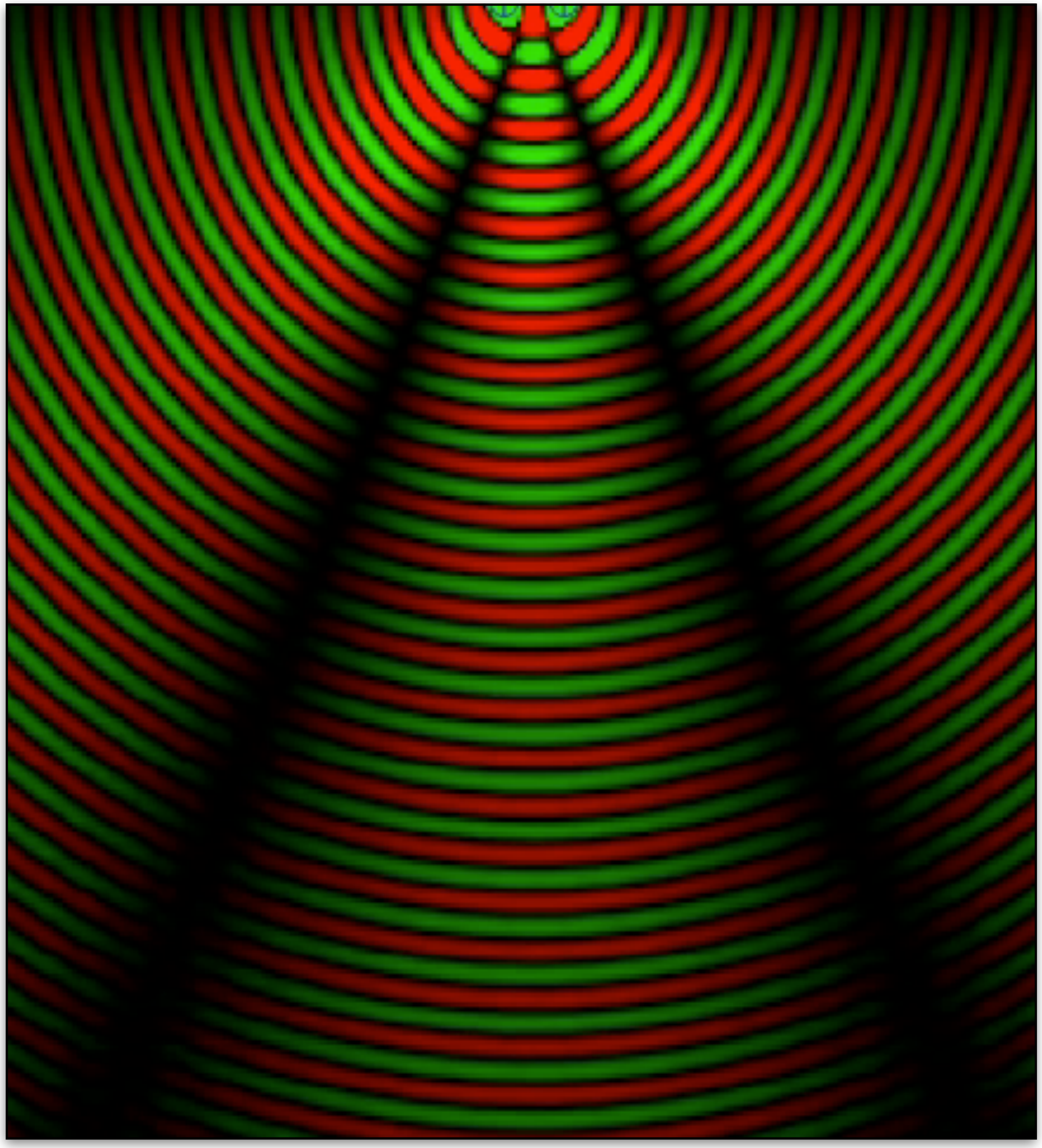
Two-Source Diffraction

- Even two identical sources of sound (same frequency and phase) can also produce a diffraction pattern
- Try this out: take two speakers playing an identical tone
- Walk in front of the speakers and you will notice quiet spots



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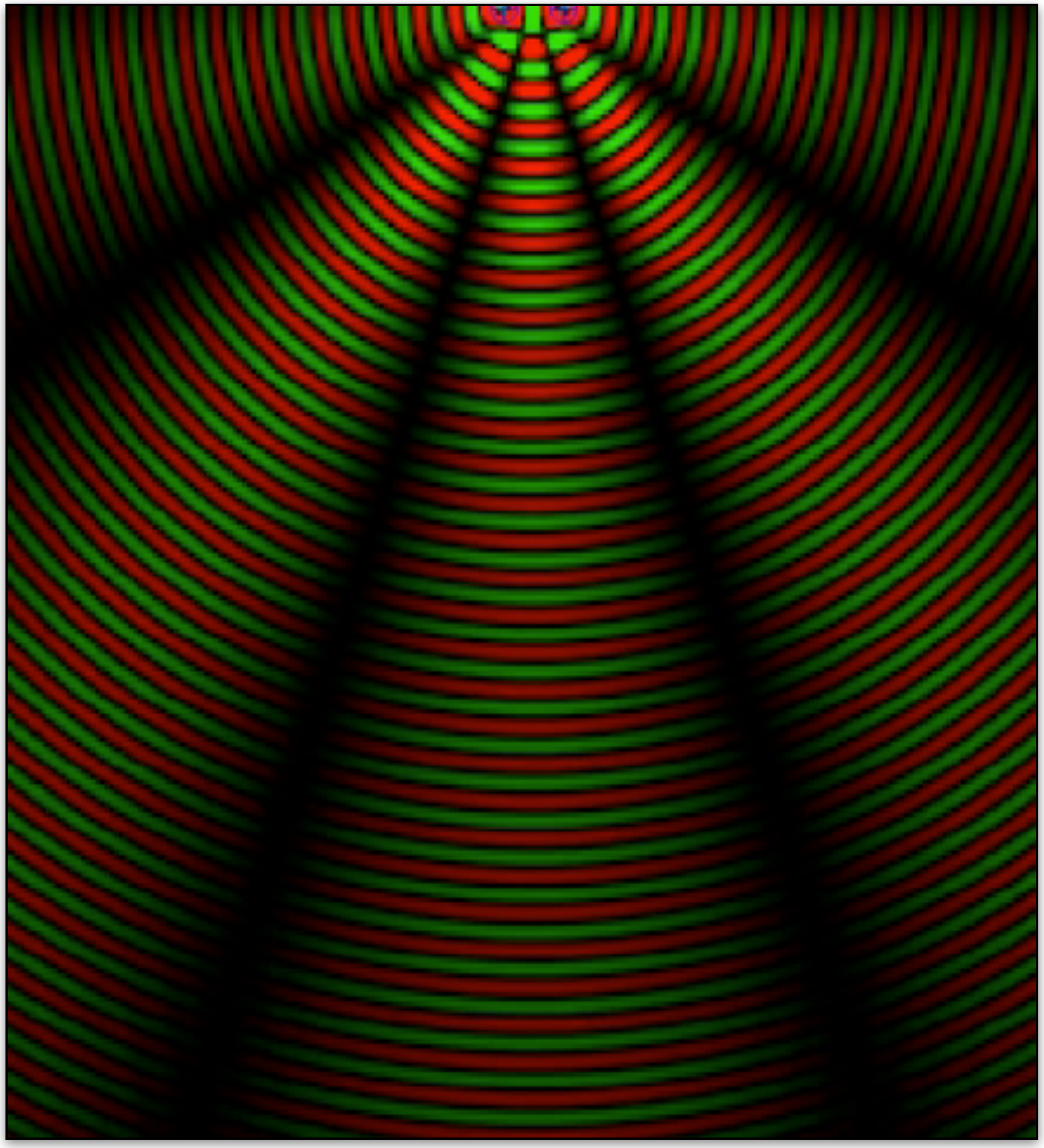
Higher-Frequency

- The diffraction pattern changes depending on the frequency of the waves
- The distinct pattern can be predicted by adding the sinusoids
- All waves exhibit diffraction. Ex: diffraction of sunlight by a double slit (T. Young, 1803)



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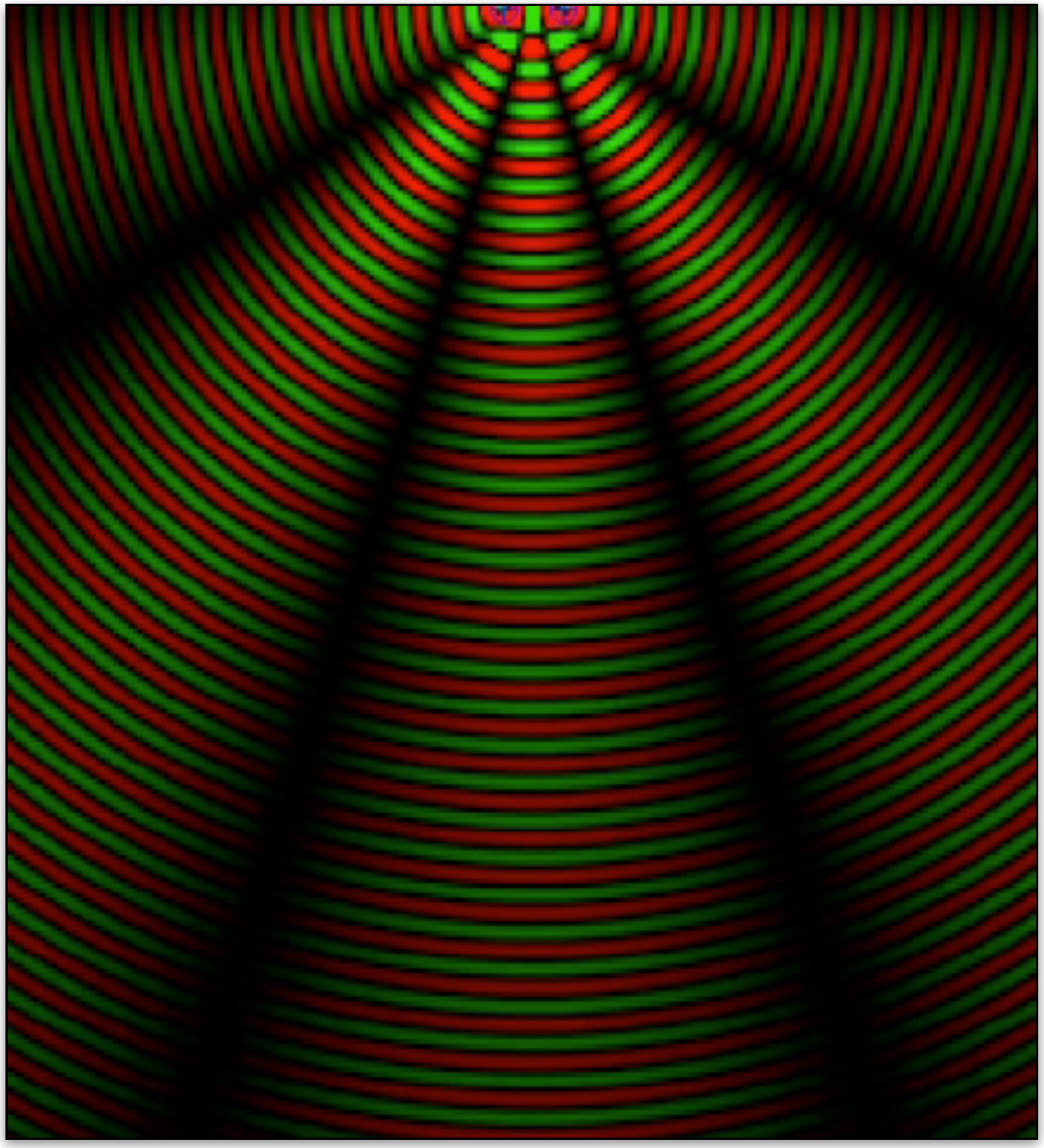

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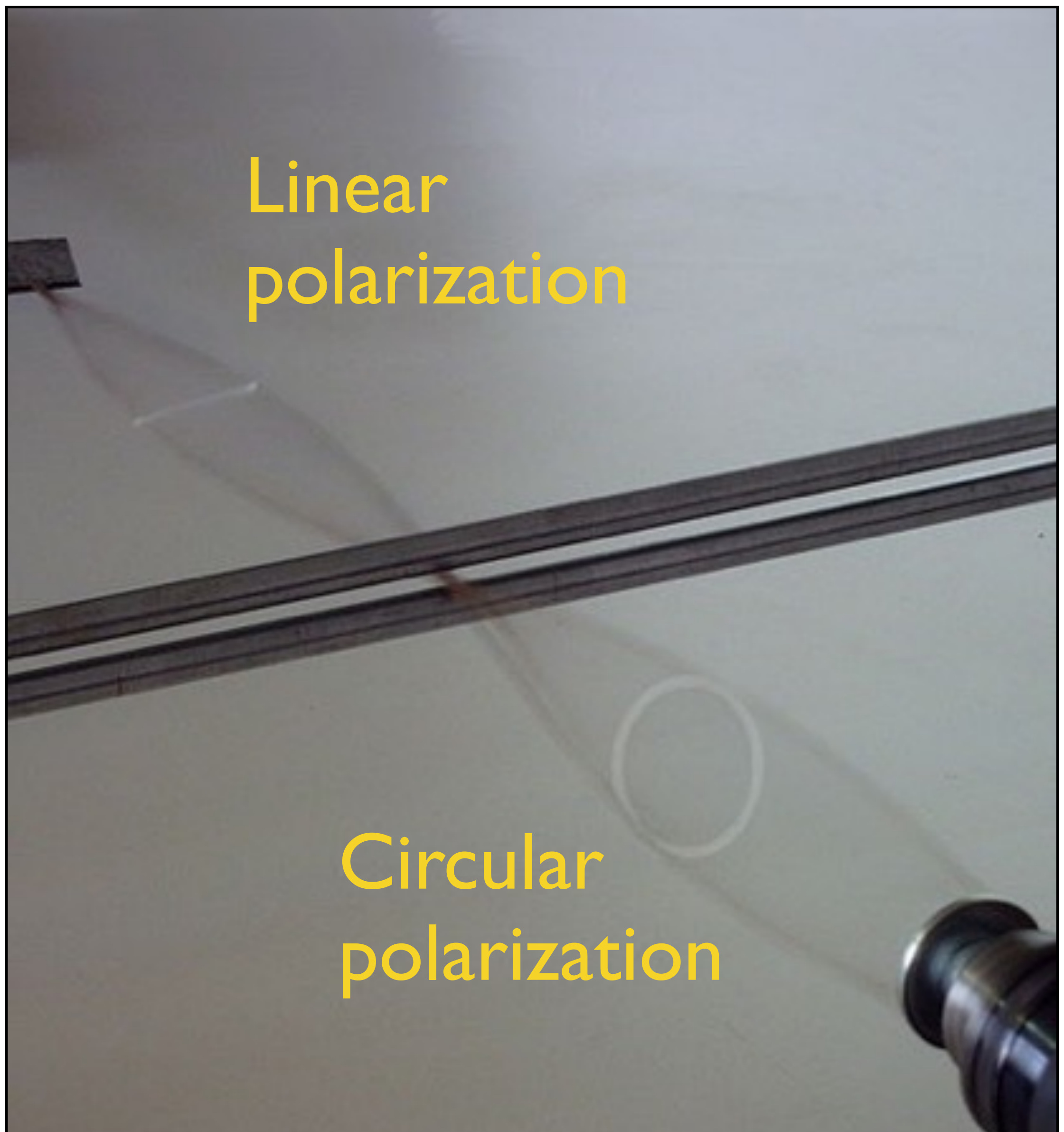
Polarization

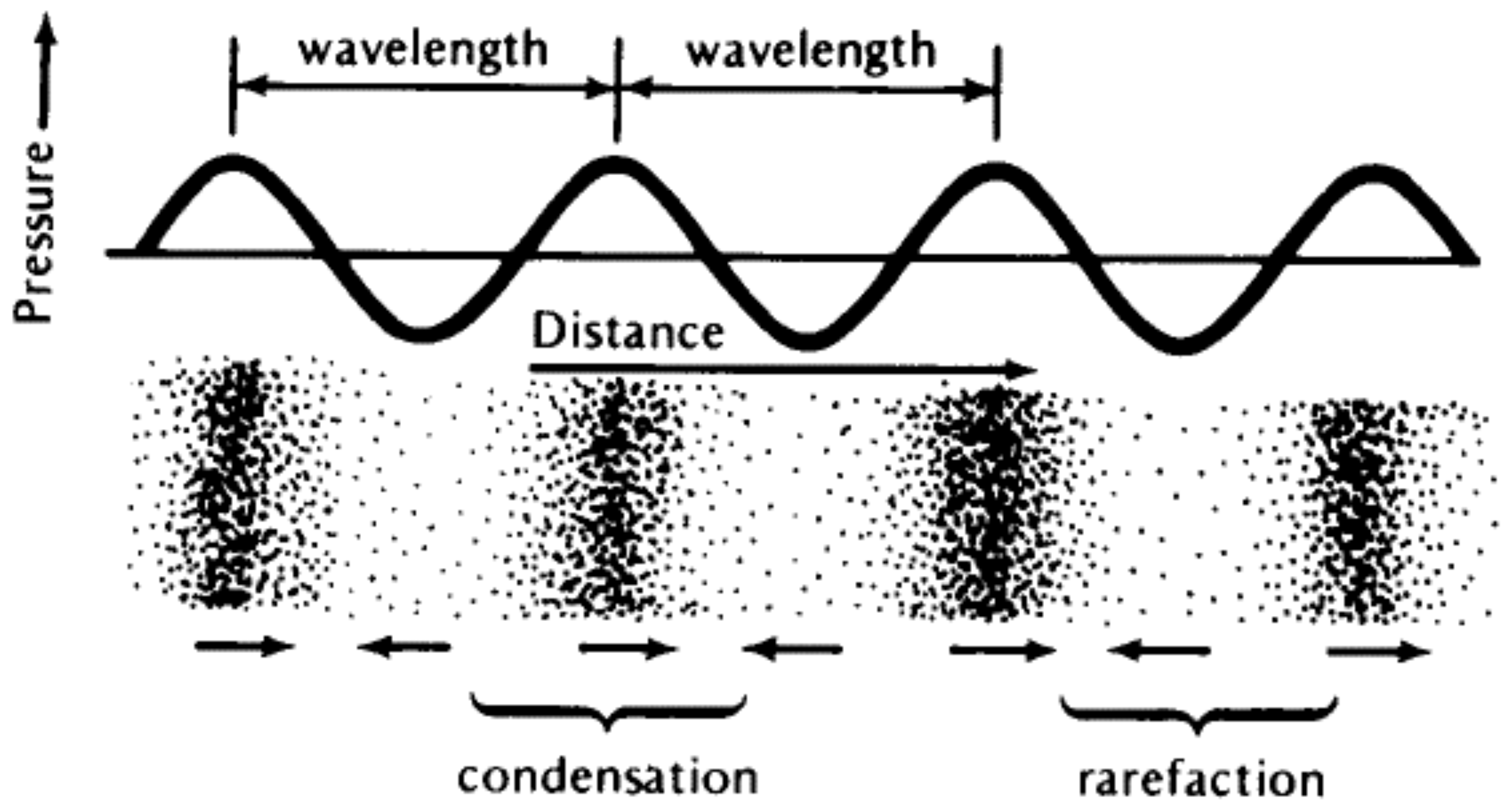
- The polarization of a wave refers to the direction of its transverse motion



- Picture a vibrating string
- The wave travels along the string
- But each segment of the string is restricted to move up and down (transverse wave)

Longitudinal Waves

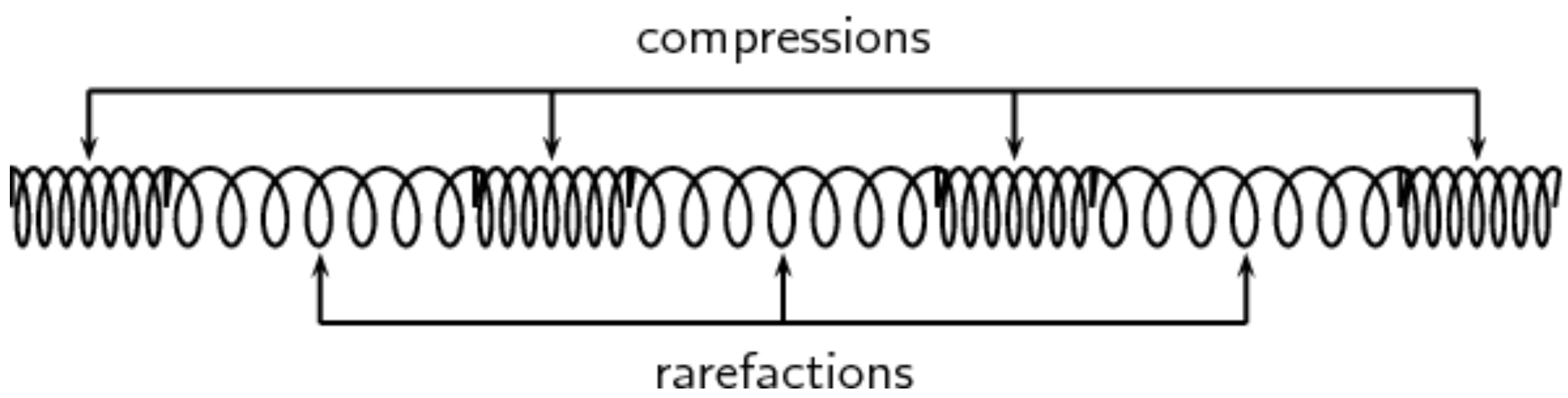
- Not all waves exhibit polarization. For example, acoustic vibrations in air are longitudinal waves



- Longitudinal wave: each segment of the vibrating material moves back and forth a bit along the direction of motion of the wave, producing areas of compression and rarefaction

The Slinky

- A good example of a longitudinal wave is the slinky
- You can send pulses back and forth along its length, making the compression/rarefaction clearly visible



- Will the speed of the pulses change as we stretch the slinky? If you have a slinky, try it yourself and see

Summary

- Wave concepts
  - Wavelength, frequency, amplitude, phase, energy
- Wave behaviors
  - Refraction, diffraction and interference, polarization
  - Longitudinal vs. transverse waves
- Next time: how waves in vibrating materials can produce sound