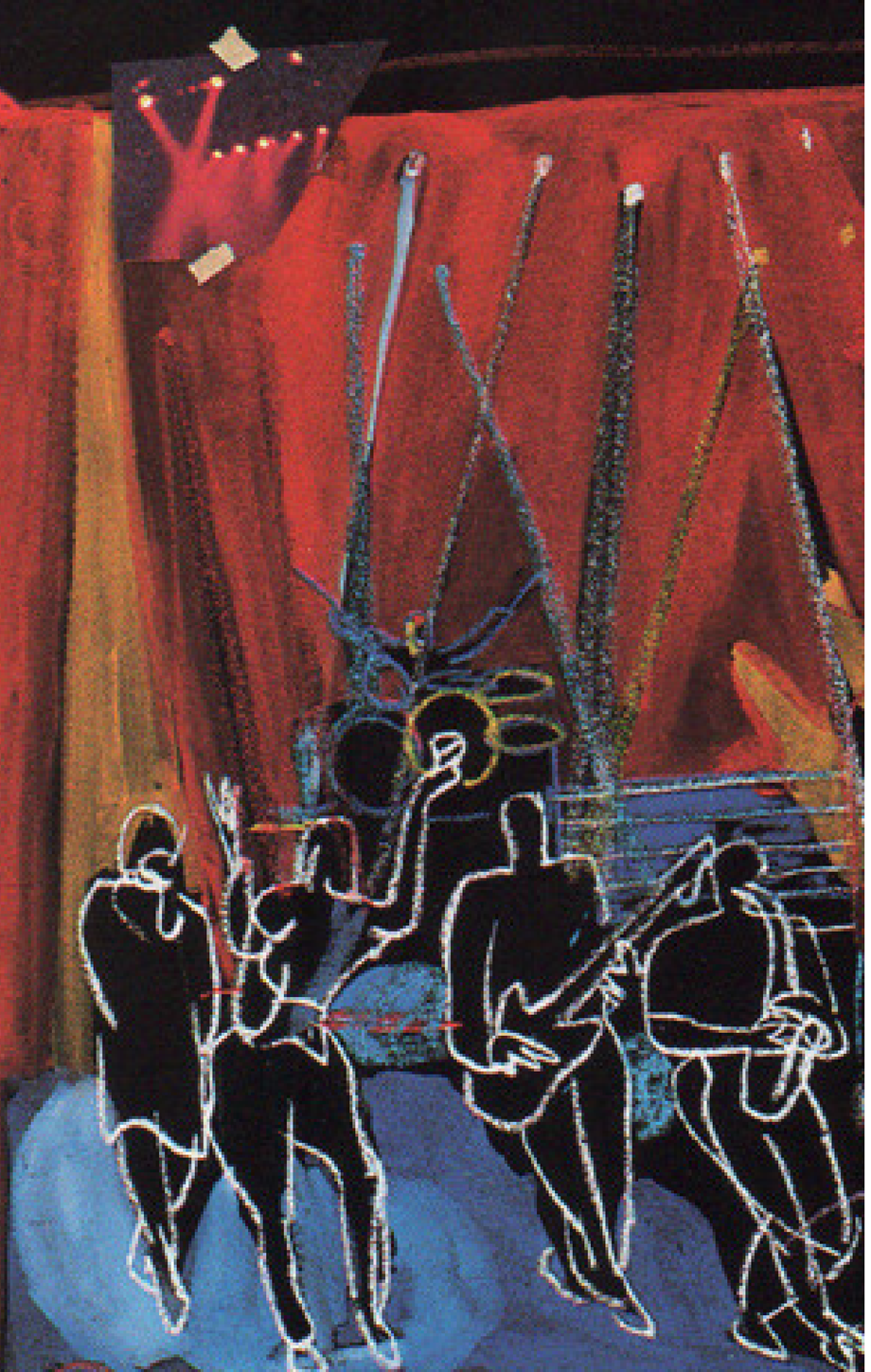


PHY-141

Doppler Effect

Luis Anchordoqui

Outline

- The Doppler effect is the change in frequency of a wave in relation to an observer moving relative to the source, causing higher pitch/frequency as it approaches and lower as it recedes
- The effect only occurs when the wave source and observer are moving toward or away from each other
- A classic example is a police car siren that sounds higher-pitched as it approaches and lower-pitched after it passes

- Thought today's class ☛ the source velocity is considered insignificant relative to the speed of sound

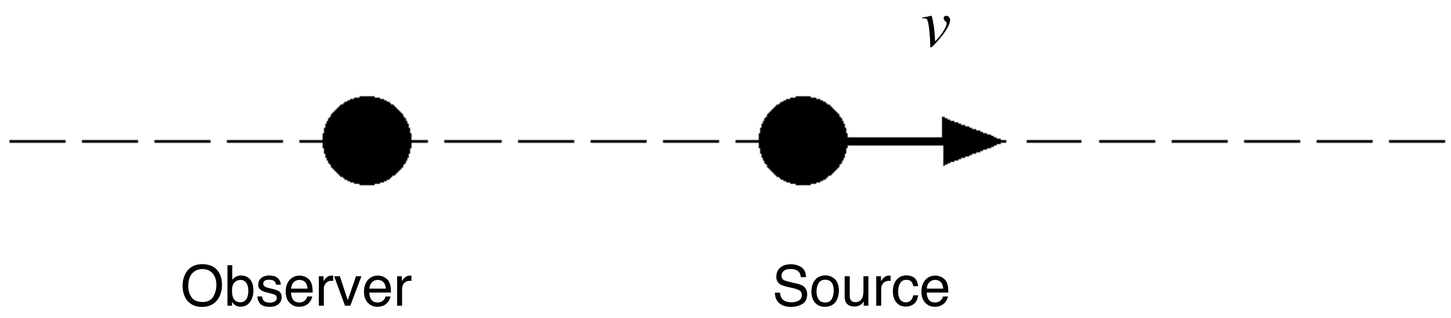
Source in Motion Observer at rest

$u \equiv$ velocity of sounds waves

$v \equiv$ recession velocity of the source

$\Delta t_S \equiv$ the period of the wave at the source

$\Delta t_O \equiv$ the period of the wave as observed



- Consider sequence events:

  (1) The source emits a wave crest

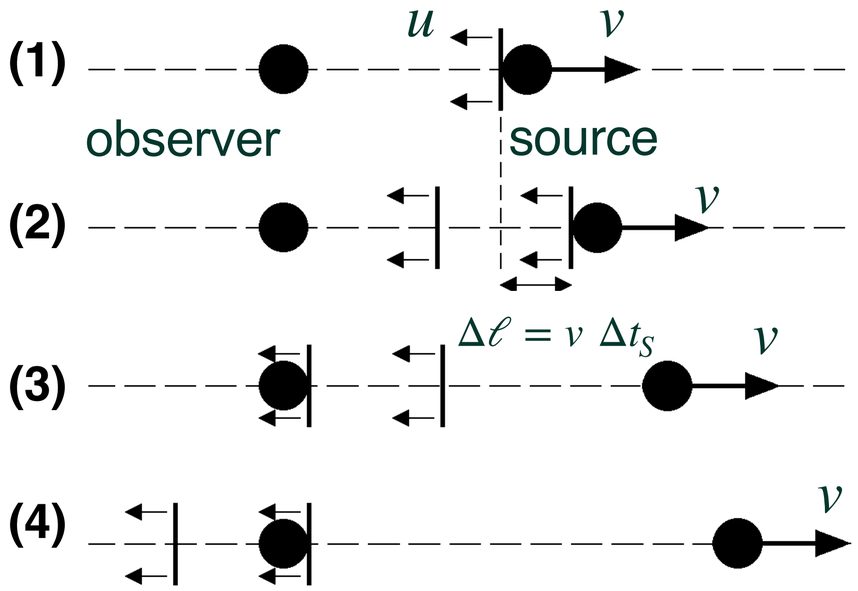
  (2) At a time Δt_S later, the source emits a second wave crest

  During this time interval the source has moved a distance $\Delta \ell = v \Delta t_S$ further away from the observer

  (3) The stationary observer receives the first wave crest

  (4) At some time Δt_O after (3), the observer receives the second wave crest

- Our goal is to find Δt_O



- We are interested only in the time difference Δt_O between the reception of the first and second wave crests
- This time difference does not depend on the distance between the source and the observer, since both wave crests have to travel this distance
- The second crest, however, has to travel an extra distance $\Delta \ell = v\ \Delta t_S$ since the source moves this distance between the emission of the two crests
- The extra time that it takes the second crest to travel this distance is $\Delta \ell / u$, so the time between the reception of the two crests is ☛

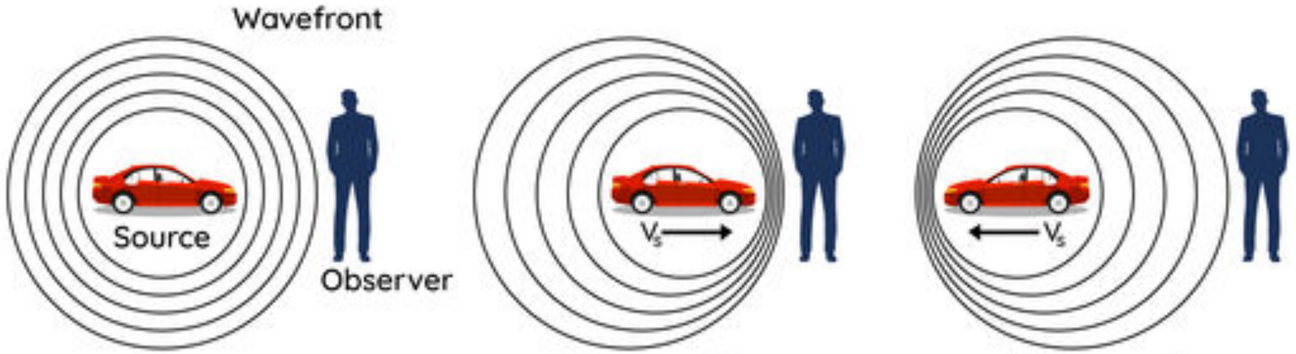
$$\begin{aligned} \Delta t_O &= \Delta t_S + \frac{\Delta \ell}{u} \\ &= \Delta t_S + \frac{v\ \Delta t_S}{u} \\ &= \left(1 + \frac{v}{u}\right) \Delta t_S \end{aligned} \qquad *$$

- If a source is moving away from stationary observer

$$f_O = f_S \frac{1}{1 + v/u}$$

$$f_O = 1/\tau_O = 1/\Delta t_O \qquad f_S = 1/\tau_S = 1/\Delta t_S$$

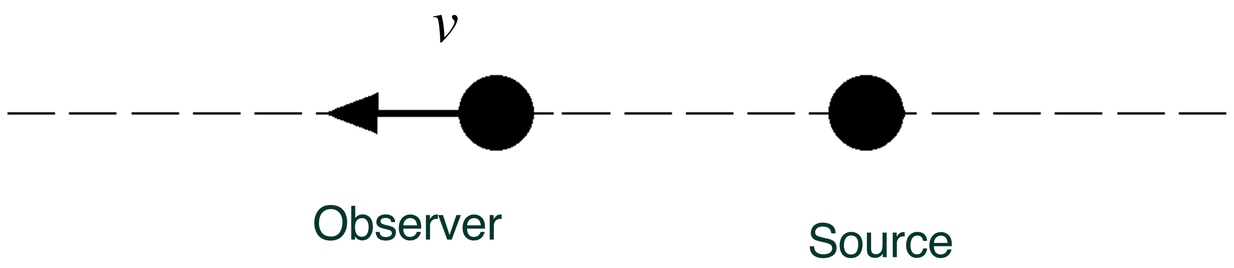
- Because the denominator is in the left-hand-side of (*) is greater than 1, the pitch heard f_O is lower than f_S



- In large-scale performances like marching bands, the physical movement of musicians can cause slight pitch shifts (the *out-of-tune* effect) perceived by the audience
- In elite performances aiming for higher precision, the rapid movement causing Doppler shifts is accompanied by high-volume, complex sounds, making the subtle pitch variations (typically only fractions of a hertz) inaudible or negligible to the audience

Observer in Motion and Source at Rest

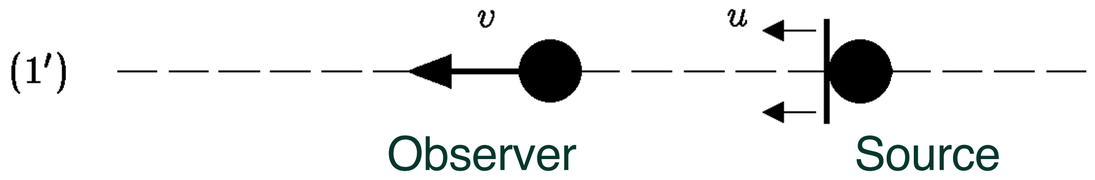
- Suppose now that the source stands still, but the observer is receding nat a speed v,



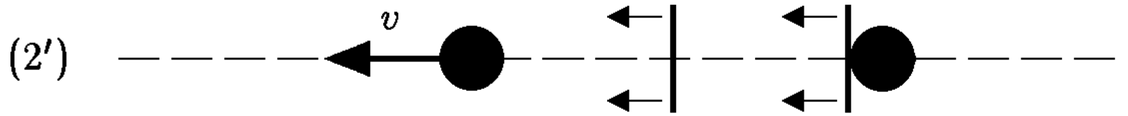
Observer in Motion and Source at Rest

➢ Sequence of events becomes

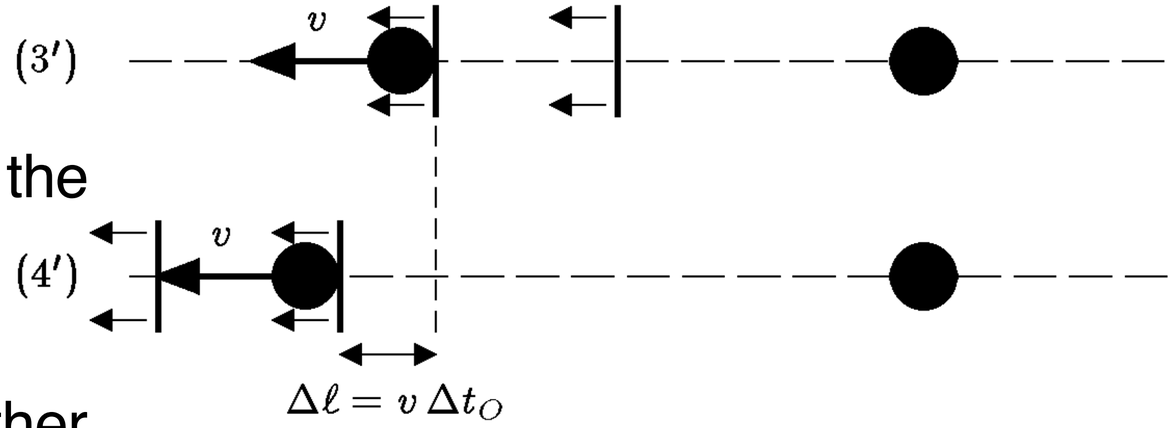
* (1')The source emits a wave crest



* (2') At a time Δt_S later, the source emits a second wave crest
* The source is standing still



* (3') The moving observer receives the first wave crest



* (4')At a time Δt_O after *(3')*, the observer receives the second wave crest
* During the time interval between (3') and (4'), the observer has moved a distance $\Delta \ell = v\Delta t_O$ further from the source

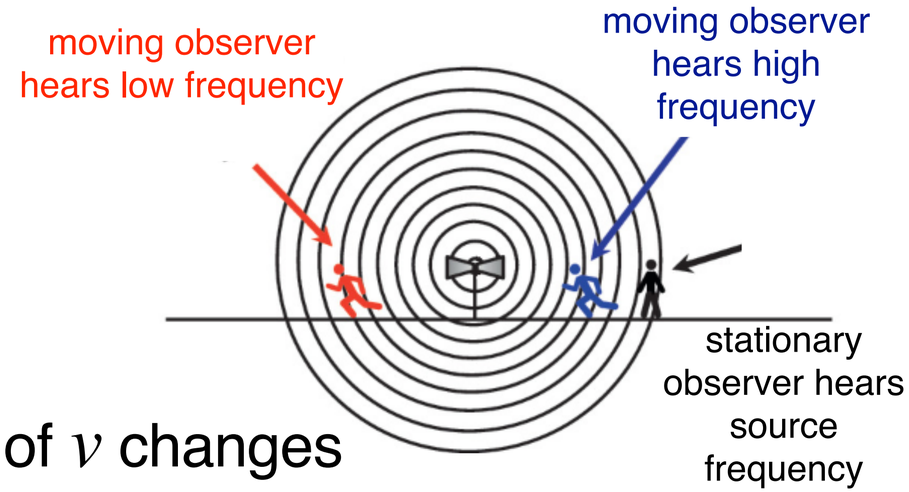
- Using the same strategy as in the first case, we note that in this case, the second wave crest must travel an extra distance $\Delta \ell = v\ \Delta t_O$
- Thus $\Delta t_O = \Delta t_S + \dfrac{\Delta \ell}{u} = \Delta t_S + \dfrac{v \Delta t_O}{u}$
- In this case Δt_O appears on both sides of the equation, but after a bit of algebra we can easily solve for Δt_O to find $\Delta t_O = \left(1 - \dfrac{v}{u}\right)^{-1} \Delta t_S$

- If observer is moving away from stationary source

$$f_O = \left(1 - \frac{v}{u}\right) f_S$$

$$f_O = 1/\tau_O = 1/\Delta t_O \qquad f_S = 1/\tau_S = 1/\Delta t_S$$

- Because $(1 - v/u) < 1$, the pitch heard f_O is lower than f_S



- If observer is moving toward stationary source, the direction of v changes
- Duplicating the steps above for an observer moving to the right, it is easily seen that the shift in the frequency is given by

$$f_O = \left(1 + \frac{v}{u}\right) f_S$$

- Because $(1 + v/u) > 1$, the pitch heard f_O is higher than f_S

What best describes the Doppler effect?

A. An increase in loudness as a source approaches

B. The change in pitch of a sound due to relative motion

C. The reflection of sound waves off a moving object

D. The bending of light as it passes through a medium

What best describes the Doppler effect?

A. An increase in loudness as a source approaches

B. The change in pitch of a sound due to relative motion

(The frequency changes, not just loudness)

C. The reflection of sound waves off a moving object

D. The bending of light as it passes through a medium

In which of the following situations is the Doppler effect absent?

A. Source moves towards a stationary observer

B. Observer moves towards a stationary source

C. Source and observer move in the same direction at the same speed

D. Both source and observer move towards each other

In which of the following situations is the Doppler effect absent?

A. Source moves towards a stationary observer

B. Observer moves towards a stationary source

C. Source and observer move in the same direction at the same speed (no relative motion)

D. Both source and observer move towards each other

When an observer walks towards a stationary speaker, the frequency they hear:

A. increases

B. decreases

C. remains the same

D. becomes zero

When an observer walks towards a stationary speaker, the frequency they hear:

A. increases

B. decreases

C. remains the same

D. becomes zero

How will your perceived frequency change if the source is moving towards you?

A. the frequency will become lower

B. the frequency will become higher

How will your perceived frequency change if the source is moving towards you?

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Bats navigate and find food using echolocation, which relies on the Doppler effect

If a bat emitting a frequency f moves towards a stationary wall, the frequency of the reflected sound (echo) detected by the bat will be:

A. lower than f

B. equal to f

C. higher than f

D. zero

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