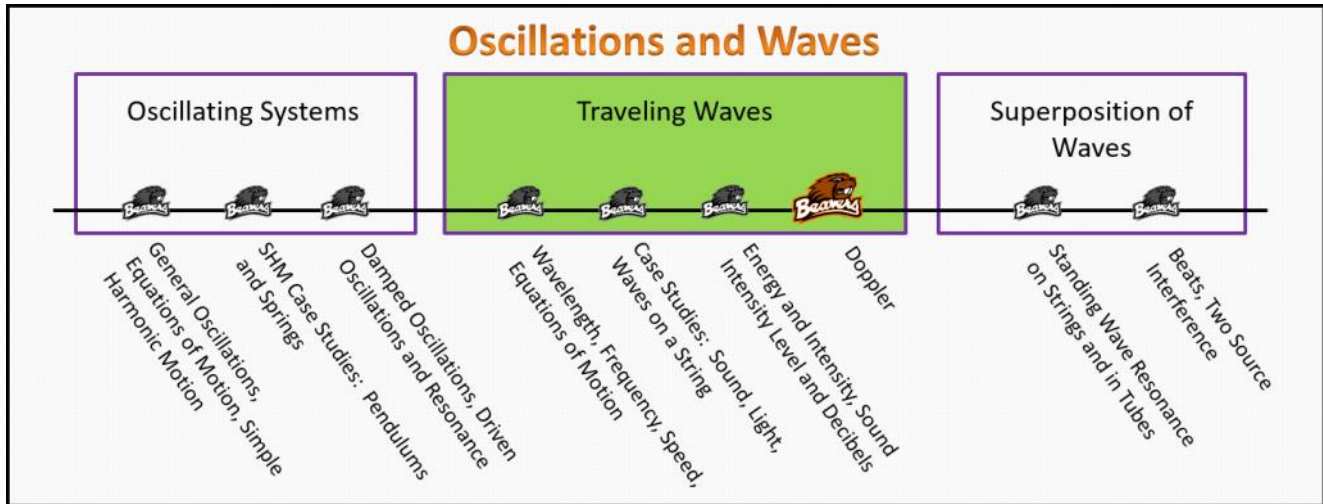


Traveling Waves

Foundation Stage (TW.2.L3)

Lecture 4 Doppler



Textbook Chapters (* Calculus version)

- **BoxSand** :: KC videos ([Doppler Shift](#))
- **Knight** (College Physics : A strategic approach 3rd) :: 15.7
- ***Knight** (Physics for Scientists and Engineers 4th) :: 16.9
- **Giancoli** (Physics Principles with Applications 7th) :: 12-7 ; 12-8 ; 12-9

Warm up

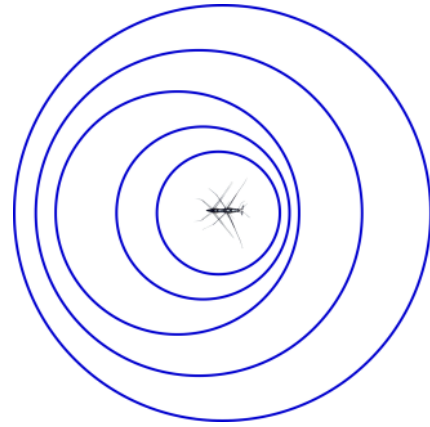
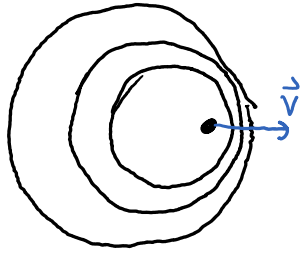
TW.2.L4-1:

Description: Conceptual question connecting wave fronts and motion of source.

Learning Objectives: [?] - Can you identify the objectives from the previous lecture, and this lecture, that this question is relevant to?

Problem Statement: The picture below is a top view of ripple waves made by a water bug on the surface of the water. From the wave pattern, we can see that the bug has been moving

- (1) continuously to the left.
- (2) continuously to the right.
- (3) back and forth, first to the left and then right.
- (4) back and forth, first to the right, and then left.
- (5) in a circle.



Selected Learning Objectives

1. Coming soon to a lecture template near you.

Key Terms

- Power
- Intensity
- Threshold of human hearing intensity
- Sound intensity level
- Decibels

IF v_0 TOWARDS SOURCE $+v_0$

IF v_0 AWAY SOURCE $-v_0$

Key Equations

$$f_o = f_s \left(\frac{v \pm v_o}{v \mp v_s} \right)$$

IF v_s TOWARDS OBS $-v_s$

IF v_s AWAY OBS $+v_s$

Key Concepts

- Coming soon to a lecture template near you.

Questions

Act I: Conceptual Questions and Visualization (sound)

TW.2.L4-2:

Description: Conceptual question about how observed frequency is affected by relative motion. (5 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: For which of the following situations will the observer hear a decreased frequency?

- (1) A source moves towards a stationary observer.
- (2) A source moves away from a stationary observer.

↓
1, 2, 1 ↑

Problem Statement: For which of the following situations will the observer hear a decreased frequency?

- (1) A source moves towards a stationary observer.
- (2) A source moves away from a stationary observer.
- (3) An observer moves towards a stationary source.
- (4) An observer moves away from a stationary source.
- (5) Observer and source are moving in the same direction but getting closer together.
- (6) Observer and source are moving in same direction but getting further apart.
- (7) Observer and source are moving in opposite directions but getting closer.
- (8) Observer and source are moving in opposite directions but getting further apart.

$|\Delta f| \uparrow$

TW.2.L4-3:

Description: Conceptual question about how observed frequency is affected by relative motion. (3 minutes + 4 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: You hear the siren from a police car and the frequency you hear is increasing.

f_s

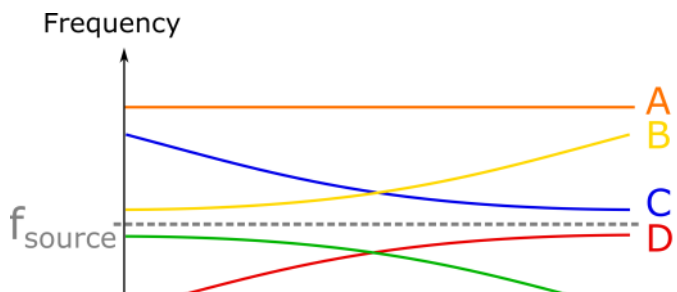
$|\Delta f| \downarrow$

(a) Which of the following can you conclude are plausible?

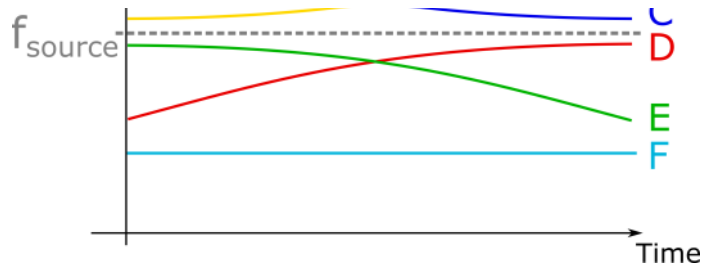
- (1) The car is receding from you at a constant speed. \sim CONST $f < f_s$
- (2) The car is receding from you at an increasing speed. \sim $f < f_s$ AND f KEEPS \downarrow
- (3) The car is receding from you at a decreasing speed. \sim $f < f_s$ AND f KEEPS \uparrow
- (4) The car is approaching you at a constant speed.
- (5) The car is approaching you at an increasing speed.
- (6) The car is approaching you at a decreasing speed.

(b) Which of the following plots match with the correct answer(s) from part (a)?

- F (1) The car is receding from you at a constant speed.
- E (2) The car is receding from you at an increasing speed.
- D (3) The car is receding from you at a decreasing speed.
- A (4) The car is approaching you at a constant speed.
- B (5) The car is approaching you at an increasing speed.



- A (7) The car is approaching you at a constant speed.
- B (5) The car is approaching you at an increasing speed.
- C (6) The car is approaching you at a decreasing speed.

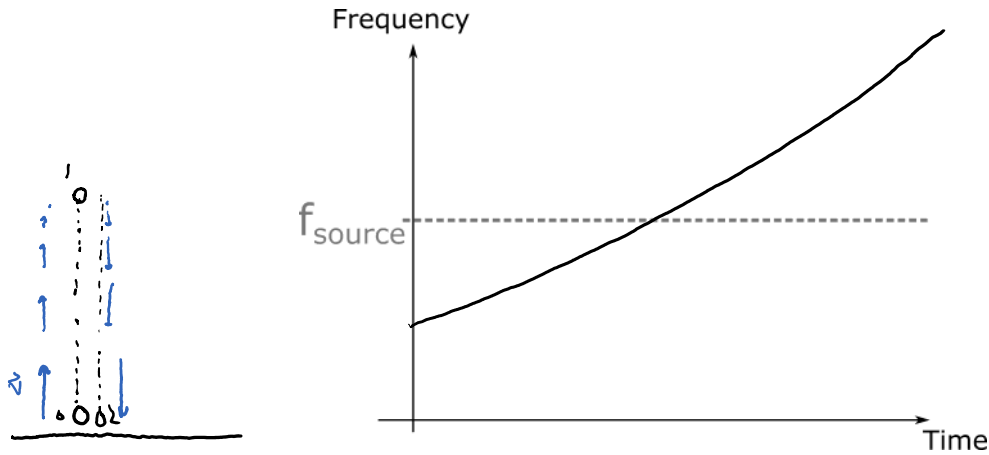


TW.2.L4-4:

Description: Conceptual question about how observed frequency is affected by relative motion. (4 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: A ball that generates a constant frequency (f_{source}) tone is thrown straight upwards above a stationary microphone. Roughly sketch on the provided plot the frequency recorded by the microphone as a function of time. Let $t = 0$ s be the time the ball leaves the hand and t_f be the moment right before the ball hits the ground.



EXTRA BONUS AFTER MATH MODEL FOR CALC CLASS

$$v_s = v_i - g\Delta t$$

$$f_o = f_s \left(\frac{v \pm v_o}{v \mp v_s} \right)$$

$$= f_s \left(\frac{v}{v + v_s} \right)$$

$$f_o = f_s \left(\frac{v}{v + v_i - g\Delta t} \right)$$

$$f_o = \frac{f_s v}{w - g\Delta t}$$

$$= \frac{f_s v}{w} \left(1 - \frac{g}{w} \Delta t \right)$$

TAYLOR SERIES

$$\approx f_s v w \left(1 + \frac{g}{w} \Delta t + \frac{g^2}{w^2} \Delta t^2 + \dots \right)$$

$$f_o = f_s \left(\frac{v}{v + v_i - g \Delta t} \right)$$

$$\approx f_s v_w \left(1 + \frac{g}{w} \Delta t + \frac{g^2}{w^2} \Delta t^2 + \dots \right)$$

FOR SMALL $\Delta t \approx$ LINEAR

TW.2.L4-5:

Description: Conceptual question about how observed frequency is affected by wind. (3 minutes).

Learning Objectives: [1, 12, 13]

Problem Statement: On a windy day, the wind blows from a stationary source to a stationary observer. Which of the following quantities change relative to a non-windy day?

- (1) Frequency of the source. \sim CONST.
 - (2) Frequency of the observer. \sim CONST. NO $|\Delta f| \downarrow$ OR \uparrow $v = 343 \pm v_{wind}$
 - (3) Speed of sound relative to the medium. $v = v_o \pm v_{wind}$
 - (4) Speed of observer relative to the medium. $v = v_s \pm v_{wind}$
 - (5) Speed of the source relative to the medium.
 - (6) Wavelength of the sound wave.
- $v = f \lambda$
 CONST \downarrow
 CHANGES SO λ MUST ALSO CHANGE

Act II: Mathematical Model (sound)

TW.2.L4-6:

Description: Calculate observed frequency for moving source and stationary observer. (2 minutes + 2 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: An opera lady running at 10 m/s while singing a constant frequency of 440 Hz is headed directly towards you as you are standing at rest. The speed of sound is 343 m/s.

(a) Which of the following mathematical models would correctly solve for the frequency you hear from the opera lady?

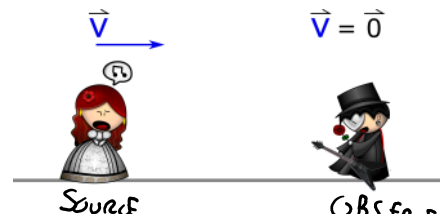
(1) $f_o = f_s \left(\frac{v}{v + v_s} \right)$

(3) $f_o = f_s \left(\frac{v - v_o}{v} \right)$

$|\Delta f| \downarrow$
so $f \uparrow$

(2) $f = f \left(\frac{v}{v} \right)$

(4) $f_o = f_s \left(\frac{v + v_o}{v} \right)$



$$(1) f_o = f_s \left(\frac{v}{v + v_s} \right) \quad (3) f_o = f_s \left(\frac{v - v_o}{v} \right) \quad \text{So } f \uparrow$$

$$(2) f_o = f_s \left(\frac{v}{v - v_s} \right) \quad (4) f_o = f_s \left(\frac{v + v_o}{v} \right)$$



(b) Calculate the frequency you observe.

- (1) 427.5 Hz
- (2) 427.2 Hz
- (3) 400.0 Hz
- (4) 452.8 Hz
- (5) 453.2 Hz

$$f_o = f_s \left(\frac{v \pm v_o}{v - v_s} \right)$$

v_s TOWARDS OBS (-)

$$f_o = f_s \left(\frac{v}{v - v_s} \right)$$

$$= 440 \text{ Hz} \left(\frac{343 \text{ m/s}}{343 \text{ m/s} - 10 \text{ m/s}} \right) \approx 453.213 \text{ Hz}$$

TW.2.L4-7

Description: Calculate observed frequency for moving observer and stationary source. (2 minutes + 2 minutes)

Learning Objectives: [1, 12, 13]

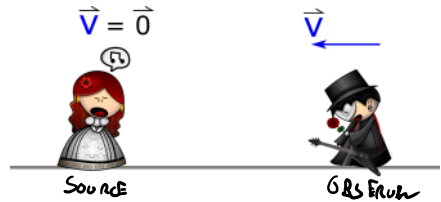
Problem Statement: You are running at 10 m/s towards a stationary opera lady singing a constant 440 Hz tone.

(a) Which of the following mathematical models would correctly solve for the frequency you hear from the opera lady?

$$(1) f_o = f_s \left(\frac{v}{v + v_s} \right) \quad (3) f_o = f_s \left(\frac{v - v_o}{v} \right)$$

$$(2) f_o = f_s \left(\frac{v}{v - v_s} \right) \quad (4) f_o = f_s \left(\frac{v + v_o}{v} \right)$$

$|\Delta f| \downarrow$
So $f \uparrow$



(b) Calculate the frequency you observe.

- (1) 427.5 Hz
- (2) 427.2 Hz
- (3) 400.0 Hz
- (4) 452.8 Hz
- (5) 453.2 Hz

$$f_o = f_s \left(\frac{v + v_o}{v} \right)$$

v_o TOWARDS SOURCE (+)

$$f_o = f_s \left(\frac{v + v_o}{v} \right)$$

$$= 440 \text{ Hz} \left(\frac{343 + 10}{343} \right) \approx 452.828 \text{ Hz}$$

* COMPARE #6 + #7

DOPPLER SHIFT FOR SOUND IS NOT SYMMETRIC... DEPENDS ON SOURCE OR OBSERVER MOVING.

TW.2.L4-8:

Description: Calculate observed frequency for moving source and moving observer. (3 minutes + 2 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: A dog is running away from a vacuum cleaner that is emitting a constant tone of 360 Hz. The dog and vacuum cleaner are moving in opposite directions. The dog's speed is 10 m/s and the vacuum's speed is 4 m/s.

(a) Which of the following mathematical models would correctly solve for the frequency the dog would hear from the vacuum cleaner?

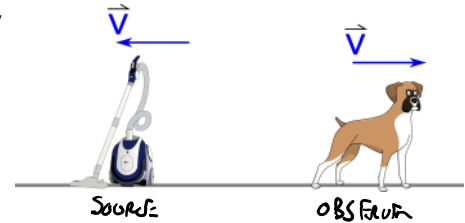
(1) $f_o = f_s \left(\frac{v + v_o}{v + v_s} \right)$ $f \uparrow$ x

(3) $f_o = f_s \left(\frac{v - v_o}{v - v_s} \right)$ $f \downarrow$

(2) $f_o = f_s \left(\frac{v + v_o}{v - v_s} \right)$ $f \uparrow$ x

(4) $f_o = f_s \left(\frac{v - v_o}{v + v_s} \right)$ $f \downarrow$

$|\Delta f| \uparrow$
So $f \downarrow$



(b) Calculate the frequency the dog observes.

- (1) 345 Hz
- (2) 353 Hz
- (3) 360 Hz
- (4) 366 Hz
- (5) 375 Hz

$$f_o = f_s \left(\frac{v - v_o}{v + v_s} \right)$$

v_o AWAY FROM SOURCE (-)

v_s AWAY FROM OBS. (+)

$$= 360 \text{ Hz} \left(\frac{343 - 10}{343 + 4} \right) \approx 345.476 \text{ Hz}$$

TW.2.L4-9:

Description: Calculate observed frequency for moving source and moving observer. (3 minutes + 2 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: A dog is running away from a vacuum cleaner that is emitting a constant tone of 360 Hz. The dog and vacuum cleaner are moving in the same direction. The dog's speed is 10 m/s and the vacuum's speed is 4 m/s.

(a) Which of the following mathematical models would correctly solve for the frequency the dog would hear from the vacuum cleaner?

(1) $f_o = f_s \left(\frac{v + v_o}{v + v_s} \right)$

(3) $f_o = f_s \left(\frac{v - v_o}{v - v_s} \right)$

$|\Delta f| \uparrow$
So $f \downarrow$



the dog would hear from the vacuum cleaner:

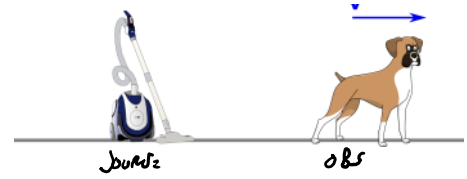
(1) $f_o = f_s \left(\frac{v + v_o}{v + v_s} \right)$

(3) $f_o = f_s \left(\frac{v - v_o}{v - v_s} \right)$

$(\Delta f) \uparrow$
So $f \downarrow$

(2) $f_o = f_s \left(\frac{v + v_o}{v - v_s} \right)$

(4) $f_o = f_s \left(\frac{v - v_o}{v + v_s} \right)$



(b) Calculate the frequency the dog observes.

$$f_o = f_s \left(\frac{v - v_o}{v - v_s} \right)$$

v_o Always from source (-)

v_s towards obs. (-)

- (1) 345 Hz
- (2) 353 Hz
- (3) 360 Hz
- (4) 366 Hz
- (5) 375 Hz

$$= 360 \text{ Hz} \left(\frac{343 - 6}{343 - 4} \right) \approx 353.6 \text{ Hz}$$

* compare #8 + 9

Both $(\Delta f) \uparrow$ so both $f \downarrow$ but

they are moving away from each other

faster to #8 so lower freq. compared to #9
345 Hz 353 Hz

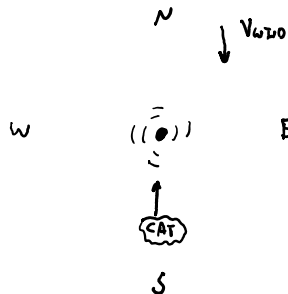
TW.2.L4-10:

Description: Calculate observed frequency for stationary source and moving observer with wind. (3 minutes + 3 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: An ideal spherical speaker is in the middle of an open field playing a constant 900 Hz tone. It's a windy day with a 5 m/s breeze blowing from the north to the south. A cat is running towards the speaker from the south to the north at 10 m/s.

(a) Which of the following mathematical models would correctly solve for the frequency the cat would hear from the speaker?



(b) Calculate the frequency the cat observes.

TW.2.L4-11:

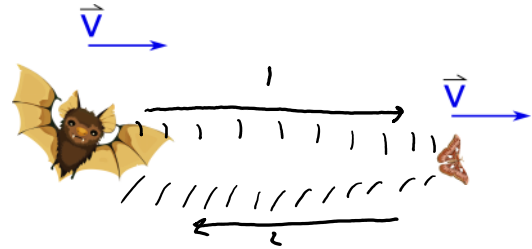
Description: Calculate observed frequency for moving source and moving observer with reflection. (1 minute + 4 minutes + 1 minute + 5 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: A bat makes a sonar click as it is flying at 4 m/s directly towards a bug that is flying at 1.2 m/s away from the bat. The frequency of the click emitted by the bat is 50 kHz. We wish to determine the frequency of the reflected click that the bat hears.

(a) How many stages should we break this problem into? For each stage, identify the source and observer.

- (1) 1 1) OBS BUG 2) OBS BAT
 (2) 2 SOURCE BAT SOURCE BUG
 (3) 3



(b) What frequency does the bug hear?

- (1) 49.25 kHz
 (2) 49.60 kHz
 (3) 50.00 kHz
 (4) 50.41 kHz
 (5) 50.77 kHz

$$f_{Bug1} = f_{Bat1} \left(\frac{v - v_o}{v - v_s} \right)$$

$$= 50 \text{ kHz} \left(\frac{343 - 1.2}{343 - 4} \right) = 50.41297935 \text{ kHz}$$

(d) What frequency does the bat hear from its reflected click off the bug?

$$f_{Bat2} = f_{Bug1} \left(\frac{v + v_o}{v + v_s} \right)$$

$$= (50.41297935) \left(\frac{343 + 4}{343 + 1.2} \right)$$

(c) What frequency sound does the bug reflect towards the bat?

- (1) 49.25 kHz
 (2) 49.60 kHz
 (3) 50.00 kHz
 (4) 50.41 kHz
 (5) 50.77 kHz

SAME FREQ AS IT HEARS

$$f_{Bat2} = 50.82 \text{ kHz}$$

Act III: Conceptual Questions (light)

TW.2.L4-12:

Description: Conceptual question about observed wavelength given relative motion of light source and observer. (3 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: All traveling waves exhibit Doppler shift when the source and observer are moving relative to each other. The mathematical model for the Doppler shift for light is not the same as it is for sound, but conceptually the same rules apply for how the

frequency increases or decreases based on the relative motion between the source and observer.

Consider a distant star that emits yellow light, which of the following colors could someone on Earth observe if the star is moving away from us?

Hint: The speed of light is constant and the wavelengths are the following ($\lambda_{\text{yellow}} = 575 \text{ nm}$, $\lambda_{\text{blue}} = 475 \text{ nm}$, $\lambda_{\text{red}} = 650 \text{ nm}$)

- (1) Blue
- (2) Yellow
- (3) Red

"RED-SHIFTED"

$3 \times 10^8 \text{ m/s}$
CONSTANT!

$c = f\lambda$

So $f \propto \frac{1}{\lambda}$

THW $\lambda_B < \lambda_Y < \lambda_R$

$f_B > f_Y > f_R$

$|\Delta f| \uparrow$ So $f \downarrow$

TW.2.L4-13:

Description: Conceptual question about what quantities can be found via Doppler shift with light from galaxies. (3 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Which of the following quantities can we determine from observations of light from a distant galaxy using Doppler shift principles?

- (1) Relative speed.
- (2) Distance to galaxy. ~ NEED HUBBLES LAW TOO BUT YES
- (3) Mass of galaxy.
- (4) Name of galaxy.

TW.2.L4-14:

Description: Conceptual question about observed frequency from light emitted by distant galaxy. (5 minutes + 5 minutes)

Learning Objectives: [1, 12, 13]

Problem Statement: Hydrogen gas (the most prevalent gas in the universe) emits a characteristic frequency of 4.57×10^{14} Hz. While observing this frequency in the galaxy below we observe the following plot.

(a) Compare the characteristic frequency of hydrogen with the frequency of the center of the "box" seen in the plot. With your neighbors, figure out a possible explanation for why the center of the box as the frequency it does.

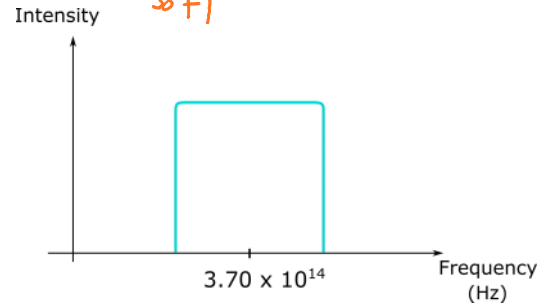
$$f_H = \underbrace{4.57 \times 10^{14} \text{ Hz}}_{\text{ON EARTH}} > \underbrace{3.7 \times 10^{14} \text{ Hz}}_{\text{OBSERVED}}$$

So $f \downarrow$ THUS CENTER OF MASS $(\Delta f) \uparrow$



(b) With your neighbors, come up with a plausible explanation for why we observe the "box" shape of the plot instead of spike at a single frequency. Hint: Where in the galaxy could the mix and max frequencies be coming from?

ROTATION OF GALAXY



Conceptual questions for discussion

1. **Coming soon to a lecture template near you.**
-

Hints

TW.2.L4-1: No hints.

TW.2.L4-2: No hints.

TW.2.L4-3: No hints.

TW.2.L4-4: No hints.

TW.2.L4-5: No hints.

TW.2.L4-6: No hints.

TW.2.L4-7: No hints.

TW.2.L4-8: No hints.

TW.2.L4-9: No hints.

TW.2.L4-10: No hints.

TW.2.L4-11: No hints.

TW.2.L4-12: No hints.

TW.2.L4-13: No hints.

TW.2.L4-14: No hints.

TW.2.L4-15: No hints.

TW.2.L4-16: No hints.

TW.2.L4-17: No hints.