Doppler Effect

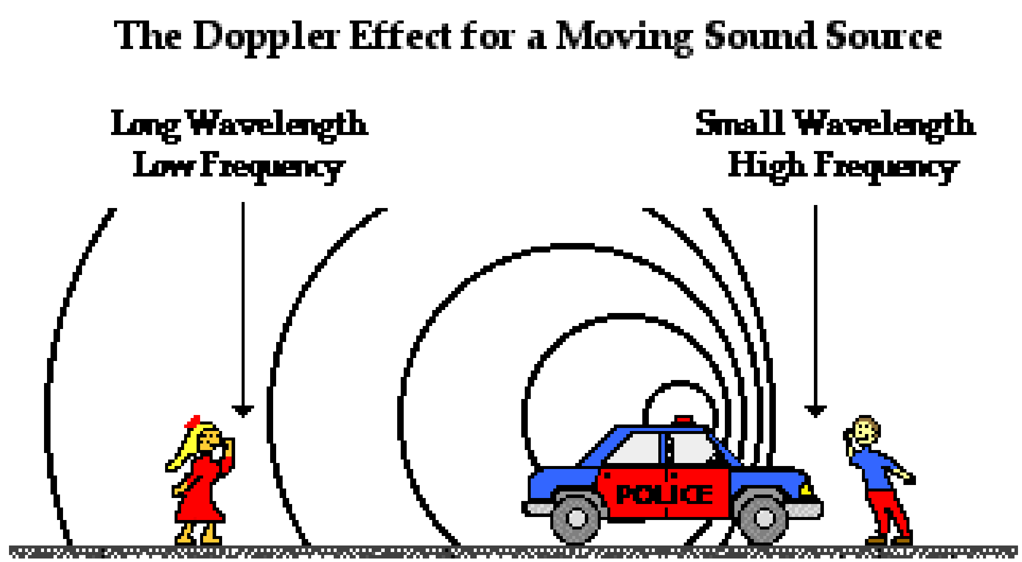
25.9 The Doppler Effect

As a wave source approaches, an observer encounters waves with a higher frequency. As the wave source moves away, an observer encounters waves with a lower frequency.

25.9 The Doppler Effect

This apparent change in frequency due to the motion of the source (or receiver) is called the **Doppler effect**.

The greater the speed of the source, the greater will be the Doppler effect.



Doppler Effect sites

- http://www2.sfu.ca/sonic-studio/handbook/Doppler_Effect.html
- http://www.fearofphysics.com/Sound/dopwhy2.htmlhttp://www.astro.ubc.ca/~scharein/a311/Sim.html#Doppler
- http://www.falstad.com/ripple/

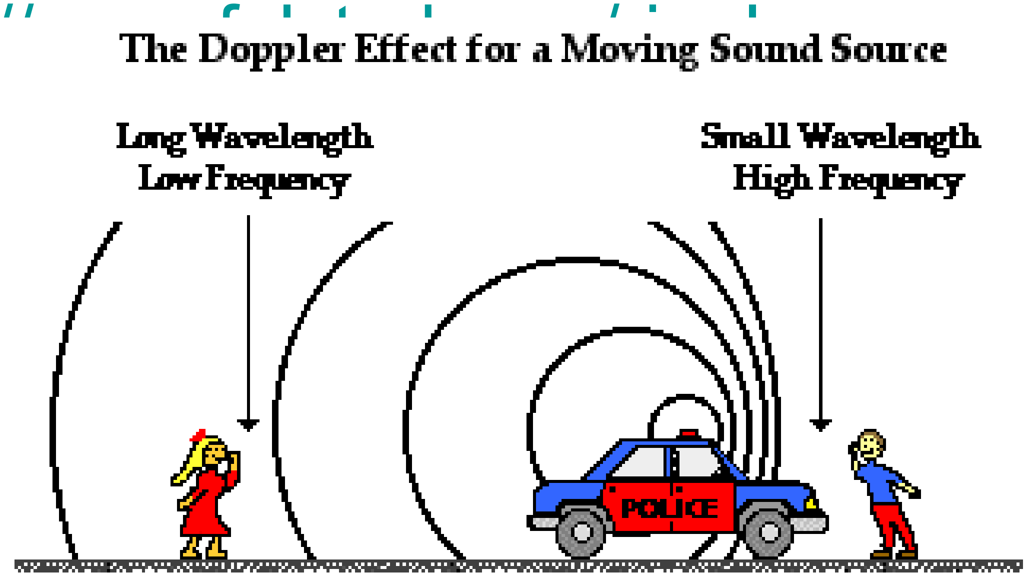
- YouTube - Fire Engine siren demonstrates the Doppler Effect

The Doppler Effect

The Doppler Effect

The apparent frequency of a sound changes due to the relative movement of the source and/or observer

http:/



YouTube - Fire Engine siren demonstrates the

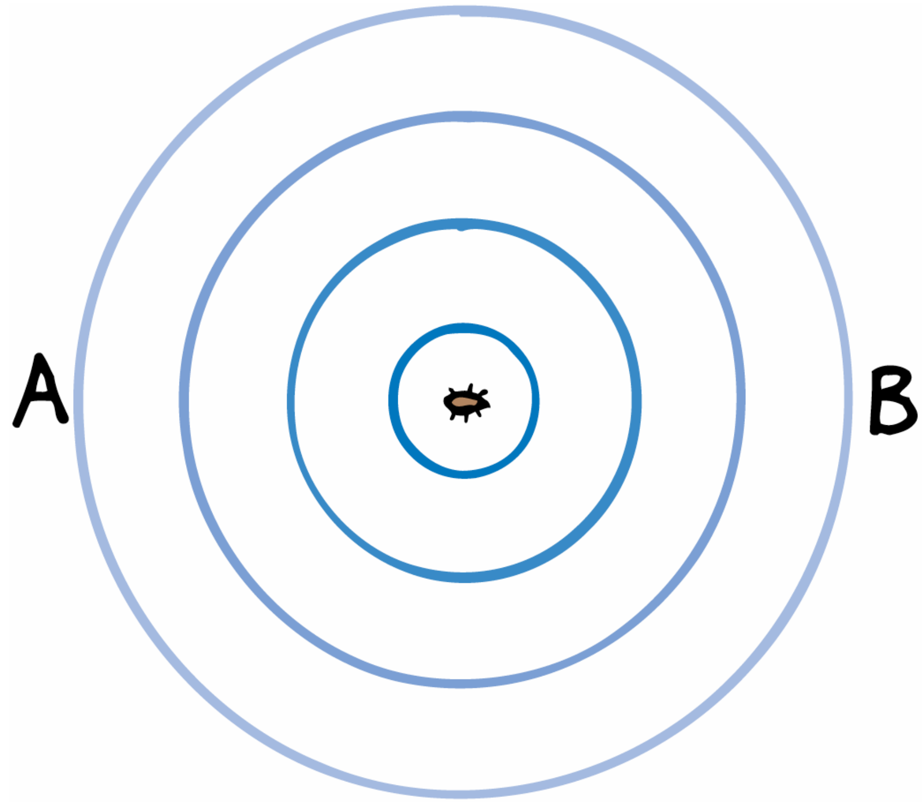
25.9 The Doppler Effect

Imagine a bug jiggling its legs and bobbing up and down in the middle of a quiet puddle.

The crests of the wave it makes are concentric circles, because the wave speed is the same in all directions.

If the bug bobs in the water at a constant frequency, the wavelength will be the same for all successive waves.

The wave frequency is the same as the bug's bobbing frequency.

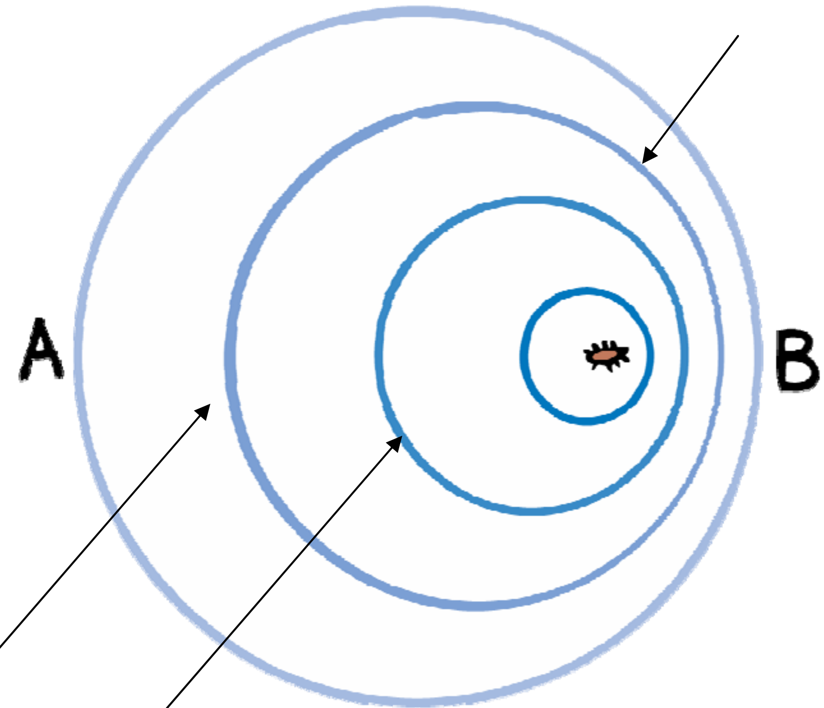


25.9 The Doppler Effect

The bug maintains the same bobbing frequency as before.

However, an observer at B would encounter a *higher* frequency if the bug is moving toward the observer.

Each wave crest has a shorter distance to travel so they arrive more frequently.



Each crest has to travel farther than the one ahead of it due to the bug's motion.

Calculating the change in frequency

Imagine a car emitting a continuous sound, speed = v, frequency = f

Sound source frequency f

Observer

Stationary Source

In a time Δt, the observer will receive fΔt waves if the source is at rest

Number of waves per second

Time in seconds

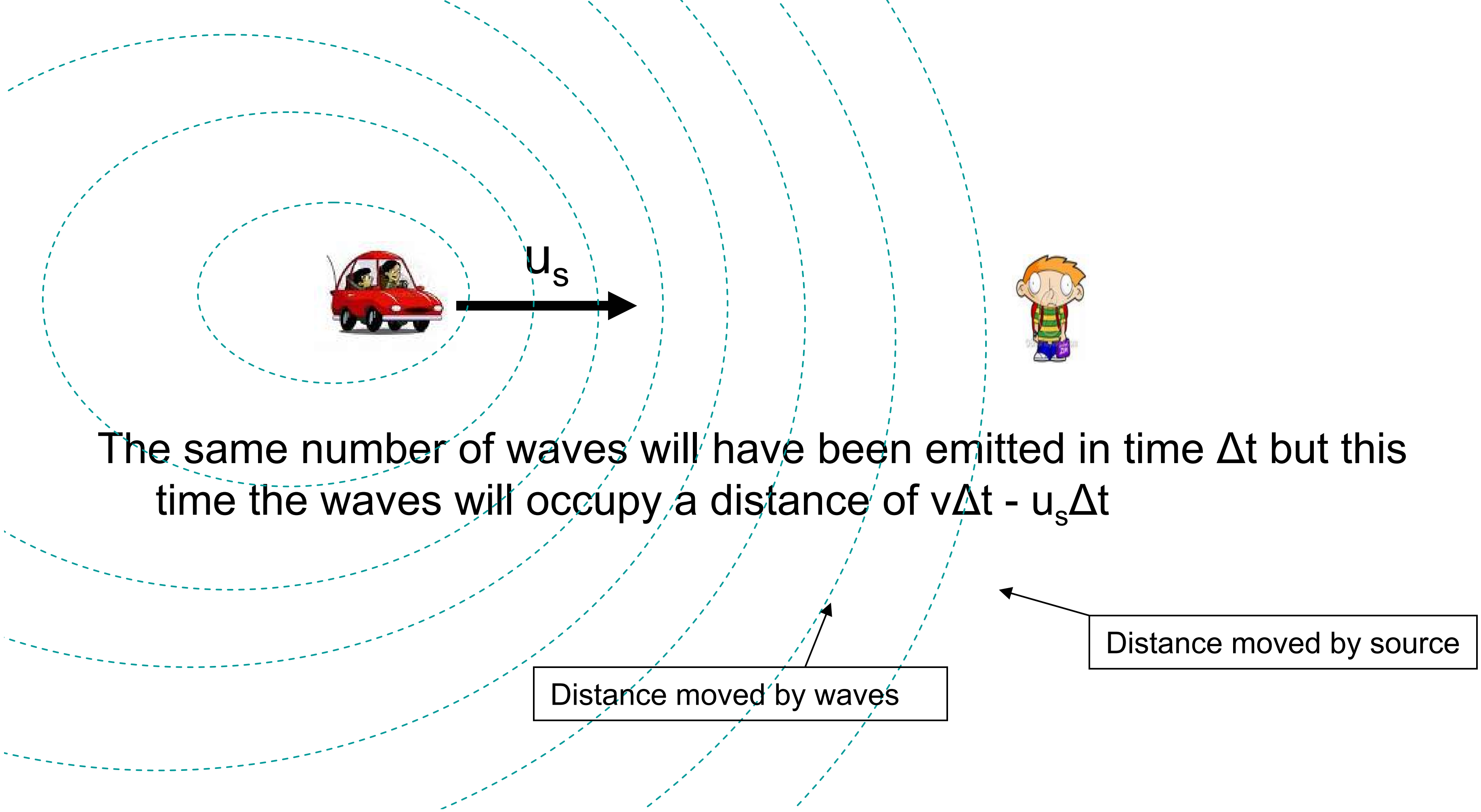
Sound source frequency f

Observer

These waves will occupy a distance vΔt (distance = speed x time)

Moving Source

If the source is now moving with speed u_s towards the observer



The same number of waves will have been emitted in time Δt but this time the waves will occupy a distance of $v\Delta t - u_s\Delta t$

Moving Source

The "new" wavelength $\lambda_n = \dfrac{\text{distance occupied by waves}}{\text{number of waves}}$

u_s →

$$\lambda_n = \frac{v\Delta t - u_s\Delta t}{f\Delta t}$$

$$\lambda_n = \frac{(v - u_s)}{f}$$

So $\dfrac{(v - u_s)}{f} = \lambda_n = \dfrac{v}{f_n}$ where f_n is the frequency heard by the observer

So $f_n = \dfrac{vf}{(v - u_s)}$

[YouTube - Doppler Effect Demonstration (Using a Little Boy)Related Videos]

If the source is moving away from the observer, $f_n = vf/\,(v + u_s)$

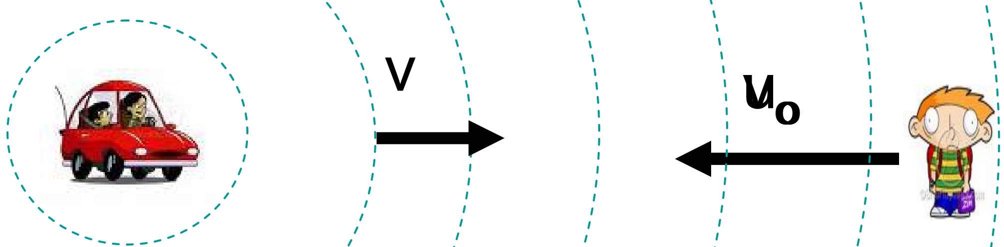
Moving Observer

Moving Observer

Imagine the observer moving towards the sound source with velocity = v_o

Imagine the observer moving towards the sound source with velocity = u_o

(Sound waves moving with velocity v)



The speed of the sound waves as measured by the observer will be $v + u_o$

Moving Observer

We therefore have a situation for the observer where $v + u_o = f_n\lambda$

Remembering that for the original wave $\lambda = v/f$

$v + u_o = f_n\lambda = f_n \times v/f$

From which

$f_n = (1 + u_o/v)f$

If the observer is moving away from the source, $f_n = (1 - u_o/v)f$

Example

- A sound wave of frequency 300 Hz is emitted towards an approaching car. The wave is reflected from the car and is then received back at the emitter with a frequency of 315 Hz. What is the speed of the car? (Take the speed of sound to be 340 $m.s^{-1}$).

The car is approaching the emitter, so the frequency the car receives is given by

$f_n = (1 + u_o/v)f = (1 + u/340)300$

The car now acts as the emitter of a wave of this frequency (f_n) and the original emitter will now act as the new (stationary) receiver. Thus the frequency received (315 Hz) is given by

$$f = 315 = \frac{vf_n}{(v - u_s)} = \frac{340}{(340-u)} \times (1 + u/340)300$$

From which we find u = 8.29 $m.s^{-1}$

25.9 The Doppler Effect

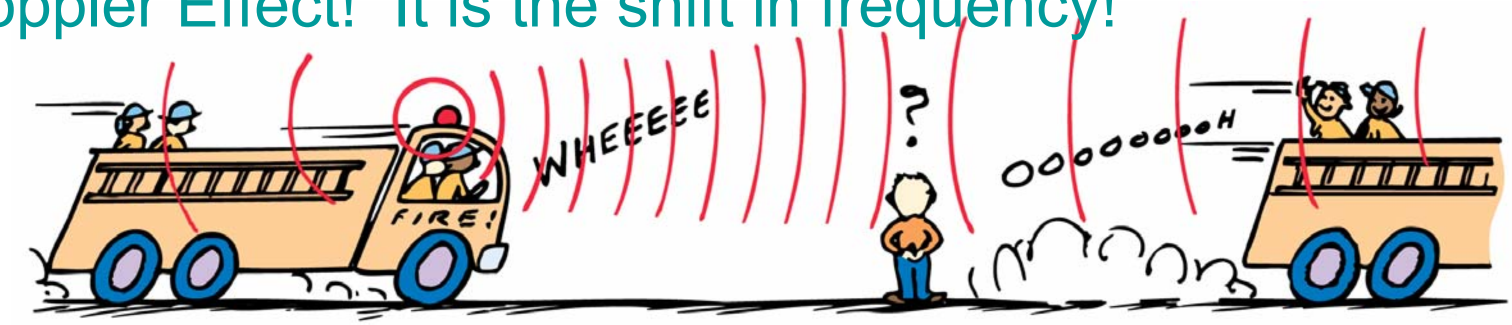
Sound

The Doppler effect causes the changing pitch of a siren.

When a firetruck approaches, the pitch sounds higher than normal because the sound wave crests arrive more frequently.

When the firetruck passes and moves away, you hear a drop in pitch because the wave crests are arriving less frequently.

Note: The change in <u>loudness</u> is not the Doppler Effect! It is the shift in frequency!

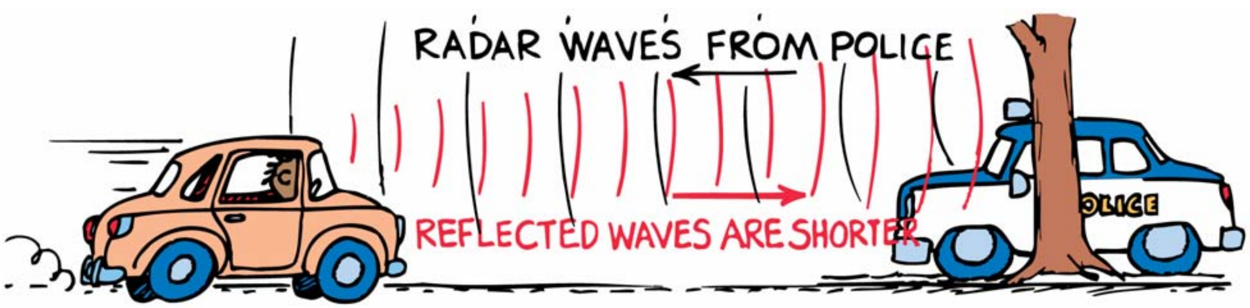


25.9 The Doppler Effect

Police use the Doppler effect of radar waves to measure the speeds of cars on the highway.

Radar waves are electromagnetic waves.

Police bounce them off moving cars. A computer built into the radar system compares the frequency of the radar with the frequency of the reflected waves to find the speed of the car.



Bats hunt moths in darkness by echo location and the Doppler effect. Some moths are protected by a thick covering of fuzzy scales that deaden the echoes.

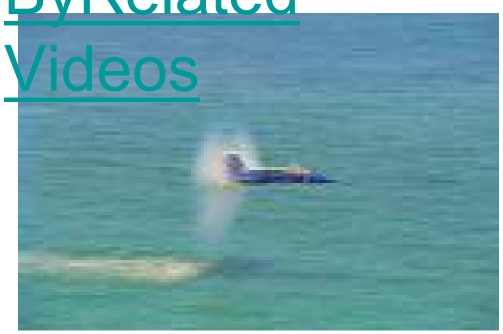
Other effects

- Don't forget that the loudness of the sound will also change as a sound source passes an observer

Other effects

- The sonic boom

[YouTube - Sonic Boom - Extreme Close Fly ByRelated Videos]



Sonic boom

- **When an airplane travels at a speed faster than sound, density waves of sound emitted by the plane cannot precede the plane, and so accumulate in a cone behind the plane. When this shock wave passes, a listener hears all at once the sound emitted over a longer period: a sonic boom. As a plane accelerates to just break the sound barrier, however, an unusual cloud might form. The origin of this cloud is still debated. A leading theory is that a drop in air pressure at the plane described by the Prandtl-Glauert Singularity occurs so that moist air condenses there to form water droplets.**

25.9 The Doppler Effect

Light

The Doppler effect also occurs for light.

- When a light source approaches, there is an increase in its measured frequency.
- When it recedes, there is a decrease in its frequency.

25.9 The Doppler Effect

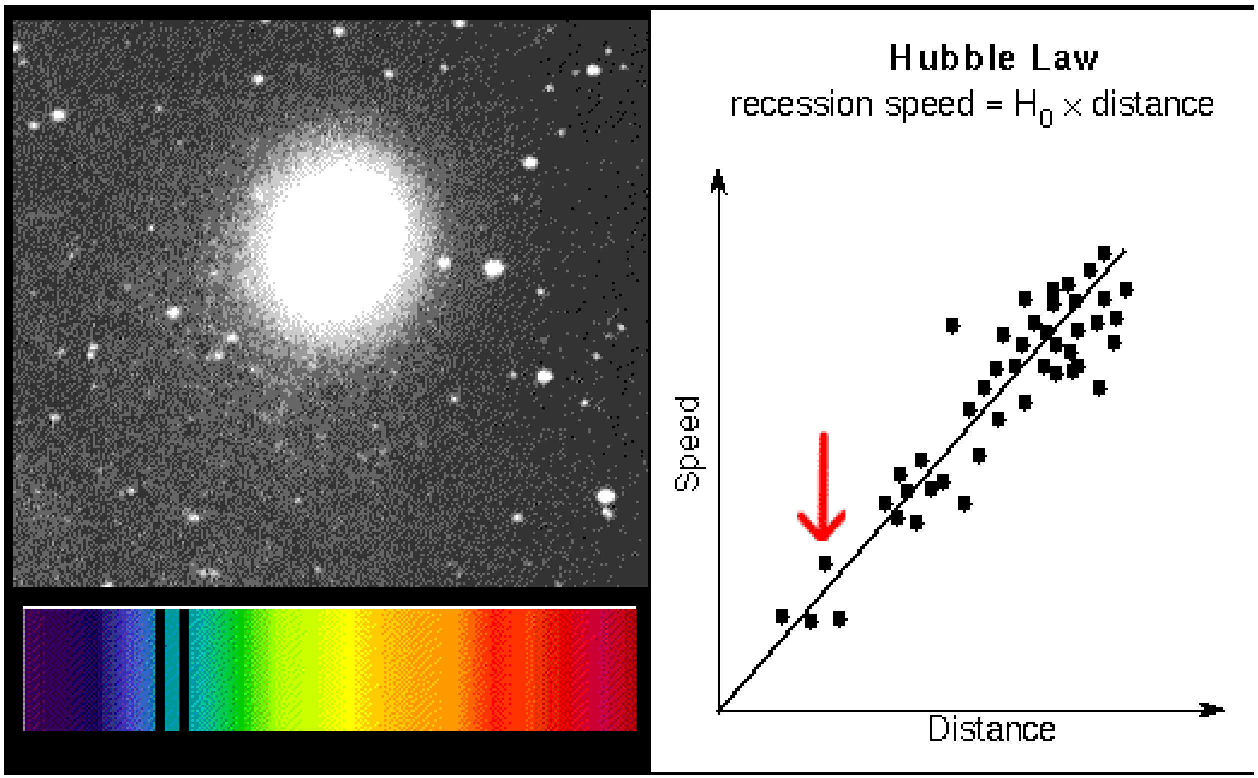
Increasing frequency is called a **blue shift,** because the increase is toward the high-frequency, or blue, end of the spectrum.

Decreasing frequency is called a **red shift,** referring to the low-frequency, or red, end of the color spectrum.

Distant galaxies show a red shift in their light. A measurement of this shift enables astronomers to calculate their speeds of recession.

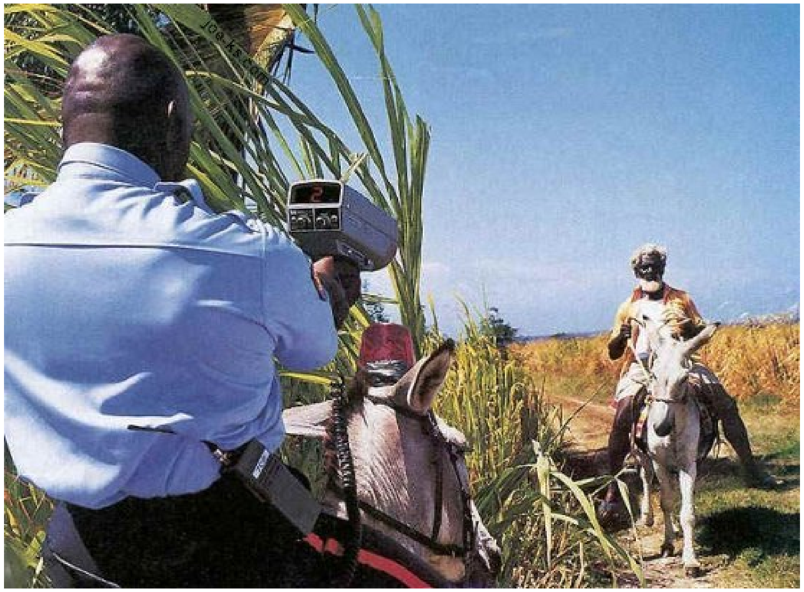
Doppler effect in light

- $\Delta f = (v/c)f$ when $v \ll c$



Uses of the Doppler effect

- Measuring the speed of moving objects (like cars or baseballs
- Measuring the speed of flow of blood cells in an artery



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25.9 The Doppler Effect

think!

When a source moves toward you, do you measure an increase or decrease in wave speed?

25.9 The Doppler Effect

think!

When a source moves toward you, do you measure an increase or decrease in wave speed?

Answer:

Neither! It is the *frequency* of a wave that undergoes a change, not the wave *speed*.

Doppler effect Space

- http://www.science
channel.com/video
-topics/space-
videos/time-
doppler-effect/

25.9 The Doppler Effect

CONCEPT CHECK

How does the apparent frequency of waves change as a wave source moves?