The Doppler Shift in Astronomy

Wavelength & Frequency

- any wave pattern has wavelength and frequency
  - wavelength is distance before pattern repeats
  - frequency is how many patterns per given time
- multiply the wavelength and frequency and you get the speed.
  - units: [distance]*[1/time]=speed
  - large wavelength means small frequency

Light & Sound

- both light and sound are wave phenomena
  - light is made of electromagnetic waves
  - sound is made of pressure waves
- for sound, high frequency means high pitch
  - middle C=261.6 Hz
  - A above middle C=440 Hz
- for light, high frequency means ”bluer” light

Source Moving toward Observer

- wave crests are closer so shorter wavelength (see more crests per second so higher frequency)
  - waves are blue-shifted (higher pitch)
- Observer moving toward source gives same result

Source Moving away from observer

- wave crests are farther so longer wavelength (see fewer crests per second so lower frequency)
  - waves are red-shifted (lower pitch)
- Observer moving away from source gives same result

Doppler Football

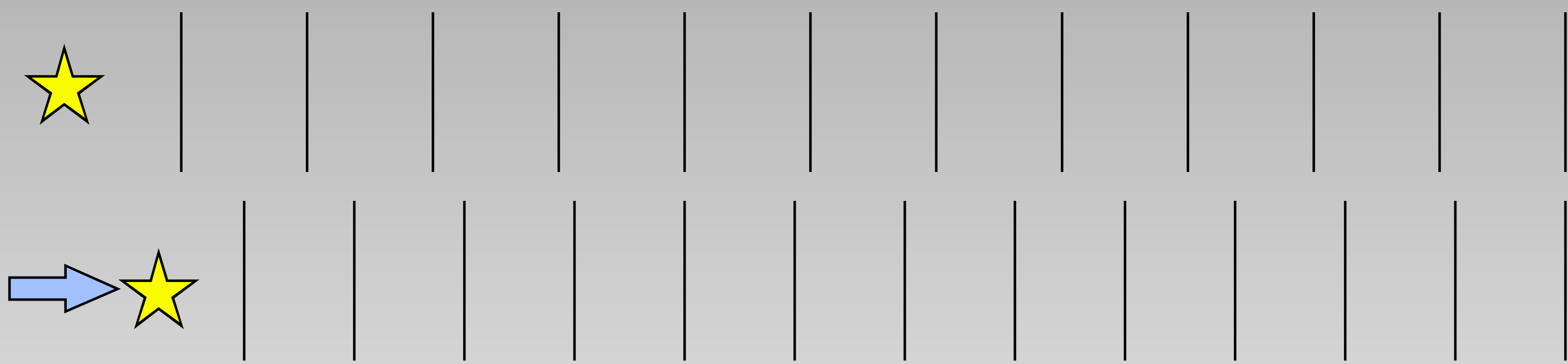
- Ingredients:
  - ❑ Nerf type football ($4)
  - ❑ piezo buzzer ($5)
    - —pure tone 2.8 kHz
    - —pulsing or continuous
    - —no drive circuit needed
  - ❑ 9V battery (?)
  - ❑ 9V battery snap connection ($1.40 for 5)
  - ❑ Flat lever switch - single throw, 2 leads ($2.80)
  - ❑ 2 rubberbands

Doppler Football

- Tools
  - wire strippers
  - Swiss army knife saw blade (cutting football)
  - electrical tape (to be safe)
- Connect one lead from buzzer to 9V (same color; strip wire as needed)
- Connect other lead from buzzer to switch
- Connect other lead from 9V to switch
  - tape as necessary
- Cut football enough to insert electronics
- Core hole in football for opening in buzzer
- Use rubberbands to “seal” football

Doppler Shift

- Shift in observed wavelength/frequency is called the <u>Doppler Shift</u>



$\lambda = c/f \quad => \quad \lambda c = 1/f$

$\lambda' = c/f + v/f$

$\lambda' = \lambda(1 + v/c)$

λ => original wavelength

λ' => observed wavelength

f => frequency

c => speed of waves

v => (vector) speed of object

Source / Observer moving perpendicular to each other

- Distance between wave crests is unaffected
- <u>No effect</u>
  - only velocity along line of sight matters

Uses of Doppler Shift

- Radar guns
  - send out radar waves
  - measure shift in return waves
- Stellar motion
  - take the spectrum of a star
  - compare observed wavelengths of absorption lines to lab values (H, Fe, Na, etc.)
  - calculate star’s radial motion (need distance and tangential angular motion to get space motion)

More uses of Doppler Shift

- Detecting planets around other stars
  - ❑ All objects orbit about the center of mass
    - —stars with large planets have larger orbits
    - —Jupiter-Sun center of mass is just outside Sun's radius
  - ❑ Watch for periodic Doppler shift as star orbits center of mass
    - —Takes Jupiter ~12 years to orbit Sun
    - —Sun's velocity is ~15 m/s
    - —Difficult observation
    - —Discoveries so far are massive planets close to the star

Still More Uses of Doppler Shift

- The Expanding Universe
  - Because universe is expanding, galaxies further away are moving faster
    - —Doppler shifted lines
  - We know wavelengths for lines of H, He, S, O (and their ions)
  - identify patterns in distant galaxy and deduce distance
- Shift is actually expansion of space
- Shift can be so large that relativity needs to be included

2 Ways EXES will use Doppler Shift

- Observing H_2O lines
  - Even from SOFIA, Earth's H_2O will block all light at certain wavelengths
  - Earth's orbit gives 30 km/s Doppler shift at maximum (Sun and target are moving, too)
  - The shift can bring source H_2O lines away from Earth's
- Disks around young stars
  - H_2 rotating in disk
  - one side comes toward you, one away
  - double-peaked spectrum