Reading: OpenStax, Chapter 19; Section 19.2
Chapter 5; Section 5.6
Chapter 17; Section 17.4

Brief review of last time: **Too small to see, too bright to ignore**

- The surfaces of the stars are too small to fully resolve
- Stellar spectra display a range of features that depend on temperature and composition; O B A F G K M

Today: **Stellar motions and the distances to the stars**

- Parallax — can measure distances to stars very accurately
- Proper motion — motion measured on the sky; stars are not fixed objects
- Radial motion and the Doppler effect — how to know if stars are moving toward or away from us
Trigonometric Parallax
Trigonometric Parallax
(do it yourself)
Trigonometric Parallax

[Diagram showing the concept of trigonometric parallax with a star, the Sun, and the Earth's orbit.]

- **June**
- **January**
- **d**
- **p**
- **nearby star**
- **distant stars**
- **2p**
Trigonometric Parallax

\[ a = d \sin(p) \]

because \( a \ll d \)

\[ d = a/p \]
Trigonometric Parallax

\[ d = a/p \]

If \( a \) is in AU (\( a = 1 \) AU) and \( p \) is in arc seconds (\( 1/3600 \) of a degree), then \( d \) is in “parsec”

\[ d = \frac{1}{p} \]
Trigonometric Parallax

distance (parsecs) = \frac{1}{\text{parallax}} (arc seconds)

d = \frac{1}{\text{p}}

• a star with a \text{parallax} of 1 arc second lies at a distance of 1 parsec (=3.26 light years)

• example: \text{α Centauri}: \text{parallax} = 0.77 arc seconds
  • d [pc] = \frac{1}{0.77} arc sec
    = 1.3 pc
  • d [ly] = 1.3 pc \times 3.26 ly/pc
    = 4.2 ly
Trigonometric Parallax

• example: $\alpha$ Centaurus: parallax = 0.77 arc seconds
  • $d \ [pc] = 1/0.77 \text{ arc sec}$
    $= 1.3 \text{ pc}$

• $d [\text{ly}] = 1.3 \text{ pc} \times 3.26 \text{ ly/pc}$
  $= 4.2 \text{ ly}$

Putting it in perspective…

• 1 arc second is about 0.5 mm as viewed over the length of one football field!

OR

• 1 arc second is about the size of the quarter viewed from 3 miles away (across the city of Ames)!!!
Limits for Trigonometric Parallax

**From Earth:**
- smallest measurable parallax: $\sim 0.01 \text{ arc sec}$
- farthest measurable distance: $\sim 100 \text{ pc}$
- nearest 20,000 stars

**From space:** the Hipparcos Mission (1989-1993)
- smallest measurable parallax: 0.0014 arc sec
- farthest distances: 700 pc
- 120,000 stars out to 700 pc
- 400,000 fainter stars out to 350 pc

**In progress:** Gaia (2013-2022)
- smallest measurable parallax: 0.000024 arc sec
- farthest distance: 40,000 pc
- brightness, position, distance to 1,700,000,000 stars
Trigonometric Parallax and Orion

From Hipparcos

https://apod.nasa.gov/apod/ap200919.html
Stellar Motions

\[ V_{\text{rad}} \]

\[ V_{\text{tan}} \]

\[ V_{\text{sp}} \]
Stellar Motions

Tangential velocity can be written in terms of “proper motion”
Proper Motion

$V_{\text{tan}} \propto PM \times d$

Can think about cars on a highway!
Example: Barnard’s Star

- $d = 1.8$ pc
- PM = $10.3''/yr$
- $V_{\tan} = 90$ km/s ($\sim 200,000$ mph)

http://www.perseus.gr/Astro-Star-Dwarf-Barnard-2010.htm
Example: Barnard’s Star

**Motion of Barnard’s Star**

- **d = 1.8 pc**
- **PM = 10.3″/yr**
- **$V_{\text{tan}} = 90$ km/s** (~200,000 mph)

[Image of a star field with labeled points and a diagram showing the motion of Barnard's Star over time.]

[Image link: http://www.perseus.gr/Astro-Star-Dwarf-Barnard-2010.htm]
Proper Motions in the Big Dipper
Proper Motions in the Big Dipper

70,000 years ago

Today

70,000 years from now
What about radial motion?

\[ V_{\text{rad}} \]

\[ V_{\text{sp}} \]

\[ V_{\text{tan}} \]
Doppler Effect
Doppler Effect (Virtual) Demo

https://astro.unl.edu/classaction/animations/light/dopplershift.html

Warning: need to enable Flash (ugh!)
Doppler Effect in Real Life

*Sound waves from a passing car*

https://www.youtube.com/watch?v=a3RfULw7aAY
The Doppler Effect is present with light waves too!

Longer wavelengths = redder light!
Called red shift!

Shorter wavelengths = bluer light!
Called blue shift!

No shift
Emission/absorption lines shift too

Reference wavelength of absorption line (i.e., no shift)

Brightness

Blue shift

Red shift
The Doppler Effect is present with light waves too!

- Longer wavelengths = redder light!
  - Called red shift!

- Shorter wavelengths = bluer light!
  - Called blue shift!

- No shift
Can calculate radial velocity from the red/blue shift of lines

\[ v_r = c \frac{\lambda_{\text{rest}} - \lambda_{\text{observed}}}{\lambda_{\text{rest}}} \]

Radial velocity

Wavelength of line observed in the star

Wavelength of line at rest (i.e., observed in a lab)
Other uses for the Doppler Effect: Stellar rotation

Broader lines!
Other uses for the Doppler Effect:
 Orbital motion
Summary of stellar positions and motions

- Use parallax to get distances to (closest) stars
- Can measure the proper motion (velocity “angle” on the sky)
- Can use both distance and angle velocity to calculate an actual velocity
- Can use the shift of spectral lines to determine radial velocity
Another advantage to knowing distance

Can calculate the actual luminosity!

\[
\text{Brightness} = \frac{\text{Luminosity}}{d^2} \quad \rightarrow \quad \text{Luminosity} = \text{Brightness} \times d^2
\]

Since we can figure out the distance (parallax), we can calculate luminosity

The spectral lines can also give us the *type* of star (OBAFGKM)
Putting all of this together: Hertzsprung-Russell Diagram

More on this next time!