**Reading:** Chapter 5, section 5.6; Chapter 17, section 17.3 - 17.4
Chapter 18, sections 18.2 & 18.4

**OBAFGKM Contest:** a better mnemonic for OBAFGKM?
- written (or e-mail) entries due Tuesday, February 27
- judging by an "independent" panel
- prizes!

**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
- Spectral line strength depends on temperature and composition
- We measure the distances to the stars through stellar parallax

**Today:** **Stellar Motions and vital statistics**
- Stars move among one another - in ways we can measure
- Motions provide more clues to stellar distance
- W/distance we can determine luminosity & do a census of the stars
- Luminosity and temperature correlate - the H-R diagram

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**Trigonometric Parallax**

- **distance (parsecs) = 1/parallax (arc seconds)**
  \[
  d = \frac{1}{p}
  \]

- a star with a **parallax** of 1 arc second lies at a distance of 1 parsec (=3.26 light years)

- **example:** α Centaurus: parallax = 0.77 arc seconds
  - \( d \ [\text{pc}] = \frac{1}{0.77} \text{ arc sec} \)
  - = 1.3 pc
  - \( d \ [\text{ly}] = 1.3 \text{ pc} \times 3.26 \text{ ly/pc} \)
  - = 4.2 ly

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**Limits for Trigonometric Parallax**

- **From Earth:**
  - smallest measurable parallax: \(~0.01\) arc sec
  - farthest measurable distance: \(~100\) 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 (2013-2018)
  - smallest measurable parallax: \(0.000024\) arc sec
  - farthest distance: 40,000 pc
  - brightness, position, distance to 1,000,000,000 stars
Stellar motion

• **Proper Motion:**
  - apparent motion across the sky, in arc sec / year
  - Barnard’s Star: 10.25 arc sec / year
  - tangential velocity $\propto$ PM $\times$ d
    - actual motion across the sky, in km/s
    - $V_{\text{tan}} = 4.74 \text{pc} \times \text{PM } /\text{yr} \times d$

• **Radial Velocity:**
  - actual speed in line-of-sight
  - determined by Doppler shift of spectral lines
    - object moving towards you: “blue shift”
    - object moving away from you: “red shift”

• **Space Velocity:**
  - true motion of star through space
  - combination of radial and tangential velocity
  - main component - reflex Solar motion (?)

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**Barnard’s Star - the Proper Motion Champion**

- **Proper Motions in the Big Dipper**
  - 70,000 years ago
  - Today
  - 70,000 years from now

- **Barnard’s Star - the Proper Motion Champion**
  - 1950
  - 2010

- **http://www.perseus.gr/Astro-Star-Dwarf-Barnard-2010.htm**
The Doppler Shift measures Radial Velocity

Solar Motion w.r.t. the Stars
- Stars appear to move as a result of
  - relative motion of stars themselves and
  - our Sun’s motion in the Galaxy
- Sun’s relative motion: 20 km/sec (towards Hercules)
- On average, closer stars appear to move faster

Secular Parallax: another distance measure
- A. Measure proper motion
- B. Measure radial velocity via Doppler shift
- C. Assume Space Velocity is reflex of mean solar motion
- D. Obtain tangential velocity using C with B
- E. Distance given by proper motion and tangential velocity:
  \[ V_{\text{tan}} = \frac{4.74 \text{ pc} \times \text{PM \"yr\" \times d}}{\text{PM}} \]
  - distance \(\propto\) tangential velocity / proper motion

aside: other uses for Doppler Effect
- Stellar Rotation
- Atmospheric motions (convection, turbulence)
- Orbital Motion
A Census of the Stars

• Observed Luminosities
  \[ \frac{L_{\text{sun}}}{100,000} > 100,000 \times L_{\text{sun}} \]

• Observed Temperatures
  \[ 2000K \quad \text{to} \quad 200,000K \]

• Classification
  stars of a given spectral type (= temperature)
  can have vastly different luminosities ranging over factors of several thousand

• Need to classify stars by spectral type and luminosity

1914: The Hertzsprung-Russell Diagram

spectral type as ‘X’; luminosity as ‘Y’

The H-R Diagram: a device to classify stars by spectral type and Luminosity (i.e. T, or color)

• Radius on the H-R Diagram
  \[ \frac{L}{L_{\text{sun}}} = \left( \frac{R}{R_{\text{sun}}} \right)^2 \left( \frac{T}{T_{\text{sun}}} \right)^4 \]
  stars at same L: Higher T → smaller R
  stars at same T: Higher L → Bigger R

• biggest stars: upper right-hand corner of H-R Diagram

Radius on the H-R Diagram
Features on the H-R Diagram

- **The Main Sequence**
  - diagonal band
  - 90% of all stars are Main Sequence stars

- **The Giants**
  - upper right
  - high L, low T -> huge size; $100 \, R_{\text{sun}}$ and more!

- **White Dwarfs**
  - lower left
  - low L, ~high T -> tiny size; $0.01 \, R_{\text{sun}}$ and less