Chapter 10
Measuring the Stars
Giants, Dwarfs, and the Main Sequence

10.1 The Solar Neighborhood

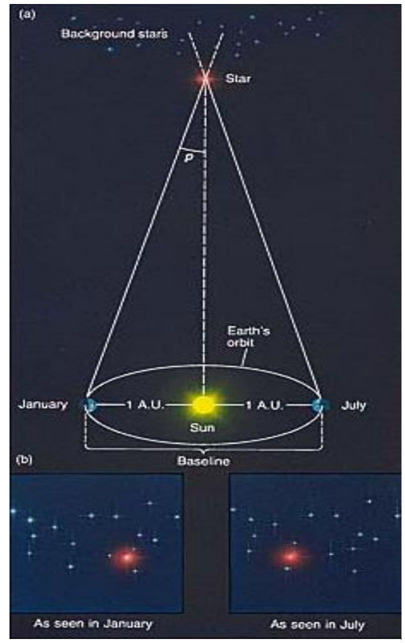
- Stellar Parallax
  - Distances to the nearest stars are very large and must be determined using stellar parallax.
  - Because the distances are so large, the angle of parallax is very small. They are measured in arc seconds (1° (degree) contains 60’ (minutes), and each 1’ (minute) contains 60” (seconds) of arc)
  - Parsec is the unit of distance from a parallax in arc seconds.
    - 1 parsec = 206,265 AU = 3.1×10^{16} m
  - The distance and parallax are inversely proportional and follow the equation:

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

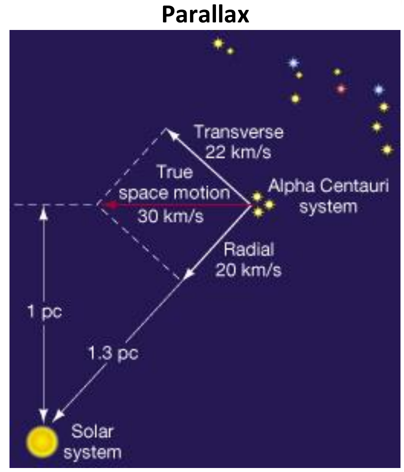
- Our Nearest Neighbors
  - The closest star to Earth is *Proxima Centauri* which has a parallax angle of 0.77” making it 1.3 pc away. This is 270,000 AU or 4.3 ly away from the Sun
  - The second closest star to the Earth is *Barnard’s Star*. Its parallax is 0.55” making it 1.8 pc or 6.0 ly from the Sun.
  - There are 30 stars within 4 pc (13 ly) from our Sun

- Stellar Motion
  - Proper Motion is the annual motion of a star in the sky corrected for parallax.
    - Transverse Velocity is the speed at which the star moves perpendicular to the Earth and can be determined using the proper motion and the distance to the star
    - Radial Velocity is the speed at which the star is moving toward or away from the Earth and can be determined by the redshift or blueshift observed in the solar spectra.
  - The star’s actual space motion is determined using the Pythagorean Theorem:

$$v_r^2 + v_t^2 = v_a^2$$



Parallax



Stellar Motion

10.2 Luminosity and Apparent Brightness

- Luminosity is the amount of radiation leaving a star per unit time
  - It is an intrinsic property that does not depend on the location or motion of the observer
  - Also referred to as the *absolute brightness*.
- Apparent Brightness is the amount of energy striking a unit area per time
  - This is what we see from Earth. The amount of the luminosity that actually gets to our eye
- Another Inverse-Square Law
  - As the radiation expands, it gets spread out over a wider area as it travels further from the source.
  - If two stars have the same luminosity, but one star is twice the distance from the observer, the star that is twice the distance will be ¼ the brightness of the closer star.
  - Just as gravity is inversely dependent upon the square of the distance, so it the apparent brightness:

$$apparent\ brightness \propto \frac{luminosity}{distance^2}$$

- The Magnitude Scale
    - The Magnitude Scale is a system of ranking stars by their apparent brightness
        - Dates back to Greek astronomer Hipparchus who ranked the naked-eye stars into 6 groups of stars based on the differences in brightness he could observe with his eyes
            - 1 being the brightest and 6 being the dimmest he could detect
        - Once modern technology was used to measure the light received from stars scientists discovered two things about the magnitude scale
            - Hipparchus's scale actually ranged by a factor of 100 in apparent brightness.
                - A magnitude 1 is actually 100 times brighter than a magnitude 6
            - The human eye can only distinguish a factor of 2.5 brightness per unit
                - $2.5^6 = 100$, so each magnitude in scale equals 2.5 times the brightness
    - Apparent Magnitude is what we refer to a magnitude in Hipparchus's ranking system
        - Ranking is based on the apparent brightness we observe
            - In today's magnitude scale, we define a change of 5 in magnitude to be exactly a factor of 100 on the scale.
            - Expansion of the numbers to allow us to rank ALL objects in space has also been allowed
                - Sun is -26.7 and is the brightest object on the scale
                - The dimmest object observed with Hubble or Keck telescopes are +30
            - The apparent magnitude scale can be misleading because objects closer to us automatically have a stronger magnitude due to inverse-square law
    - Absolute Magnitude is an object's apparent magnitude if viewed from a distance of 10 pc.
        - Because the distance is fixed in the definition, it is a measure of the star's absolute brightness, also known as its luminosity.
            - Sun's absolute magnitude is only 4.8 meaning that it would barely be visible to us if it were 10 pc away rather than a mere 1 AU (93,000,000 miles)

10.3 Stellar Temperature

- Color and the Blackbody Curve
    - Remember that the intensity of the radiation given at various wavelengths will produce a blackbody curve and that the peak of that curve will correspond to a specific temperature
        - The higher the frequency, the shorter the wavelength, meaning more energy/temperature
        - The lower the frequency, the longer the wavelength, meaning less energy/temperature
- Stellar Spectra
    - Analysis of the spectra of stars can be matched to known spectra of the naturally occurring elements to determine the temperature of the star because all stars are composed of almost identical elements; just the temperature at which they burn is different.
    - There are four main differences between the spectra for the various temperatures of stars
        - Stars having surface temperatures above 25,000 K show strong absorption lines of singly ionized helium which are not present in cooler stars
        - Hydrogen absorption lines in very hot stars are relatively weak due to the temperatures not allowing hydrogen to exist, but rather ionized hydrogen
        - Hydrogen lines are strongest in stars having temperatures around 10,000 K
        - Hydrogen lines are weak in stars with temperatures below 4,000 K due to not enough energy to keep electrons out of ground state for hydrogen. The most intense lines for cool stars are from the heavier elements composing the star that do have enough energy to be out of the ground state

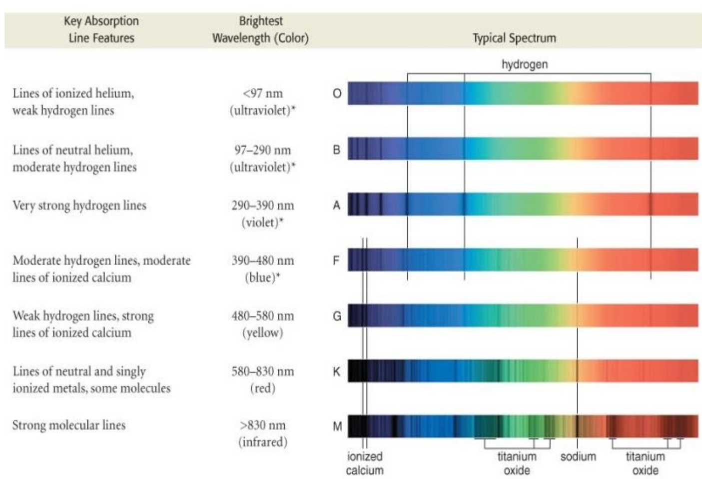


Table of Stellar Spectra

- Spectral Classification
    - Stars are given a classification based on their temperatures
        - Stars are always ordered from hottest to coolest
    - There used to be a letter classification from A-P, but with better technology and measurements, a decision to drop many of them and just use a grouping of 7 was made.
        - The seven still use their original letter designation, but are in a different order
        - There are 10 subdivisions within each class ranging from 0-9
            - 0 is the brightest
            - 9 is the dimmest
    - Pneumonic to remember the order of the spectral classes:
        - "**O**h **B**e **A** **F**ine **G**uy/**G**irl, **K**iss **M**e" = OBAFGKM

Spectral Type	Example(s)	Temperature Range	Key Absorption Line Features	Brightest Wavelength (color)
O	Stars of Orion's Belt	>30,000	Lines of ionized helium, weak hydrogen lines	<97 nm (ultraviolet)*
B	Rigel	30,000 K–10,000 K	Lines of neutral helium, moderate hydrogen lines	97–290 nm (ultraviolet)*
A	Sirius	10,000 K–7,500 K	Very strong hydrogen lines	290–390 nm (violet)*
F	Polaris	7,500 K–6,000 K	Moderate hydrogen lines, moderate lines of ionized calcium	390–480 nm (blue)*
G	Sun, Alpha Centauri A	6,000 K–5,000 K	Weak hydrogen lines, strong lines of ionized calcium	480–580 nm (yellow)
K	Arcturus	5,000 K–3,500 K	Lines of neutral and singly ionized metals, some molecules	580–830 nm (red)
M	Betelgeuse, Proxima Centauri	<3,500 K	Molecular lines strong	>830 nm (infrared)

* All stars above 6,000 K look more or less white to the human eye because they emit plenty of radiation at all visible wavelengths.

10.4 Stellar Sizes

- Direct and Indirect Measurements
    - Direct measurement of stellar size can be determined for stars close enough that an angular diameter can be measured and is calculated using the equation:

$$\frac{diameter}{2\pi(distance)} = \frac{angular\ diameter}{360°}$$

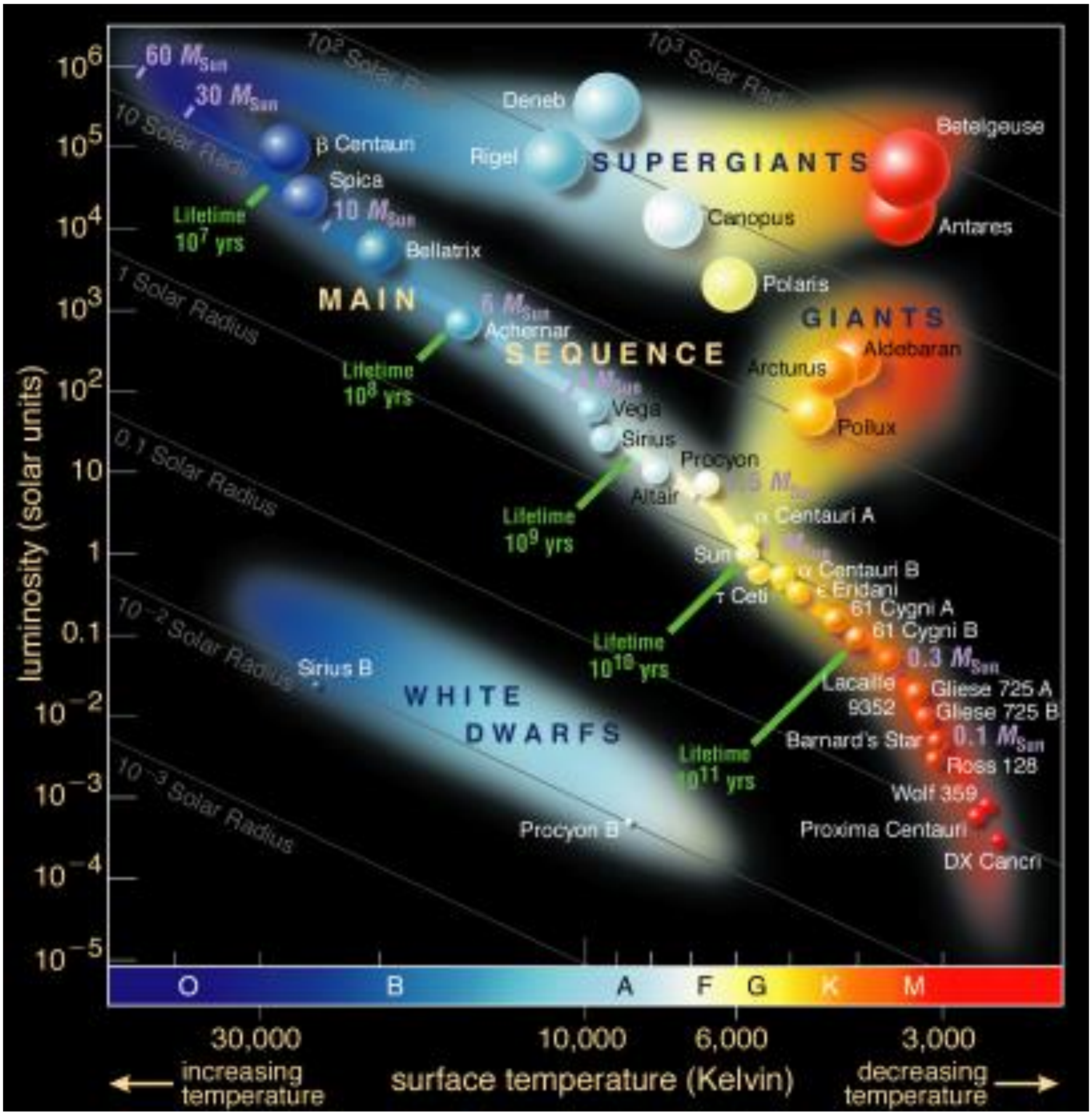
    - Indirect measurement of stellar size is calculated for stars too far away to measure angular diameter and is calculated using the Stefan-Boltzman Law
        - Stefan-Boltzman Law states that the rate at which a star emits energy into space (its luminosity) is proportional to 4^{th} power of the temperature of the star, but is also proportional to the surface area of the star. The equation for this is called the Radius-Luminosity-Temperature Relationship:

$$Luminosity \propto r^2T^4$$

- Giants and Dwarfs
    - Giants are stars having a radius between 10 and 100 solar radii
        - Red Giants are stars that are between 10 and 100 solar radii and give off red light
        - Blue Giants are stars that are between 10 and 100 solar radii and give off blue light
    - Supergiants are stars having a radius greater than 100 solar radii and can be up to 1000 solar radii
        - Red Supergiants are stars that are larger than 100 solar radii and give off red light
        - Blue Supergiants are stars that are larger than 100 solar radii and give off blue light
    - Dwarfs are stars having a radius similar or smaller to the sun's radius
        - White Dwarfs are starts that are similar or smaller than the sun and give off white light
        - Red Dwarfs are stars that are similar or smaller than the sun and give off red light

10.5 The Hertzsprung-Russell Diagram

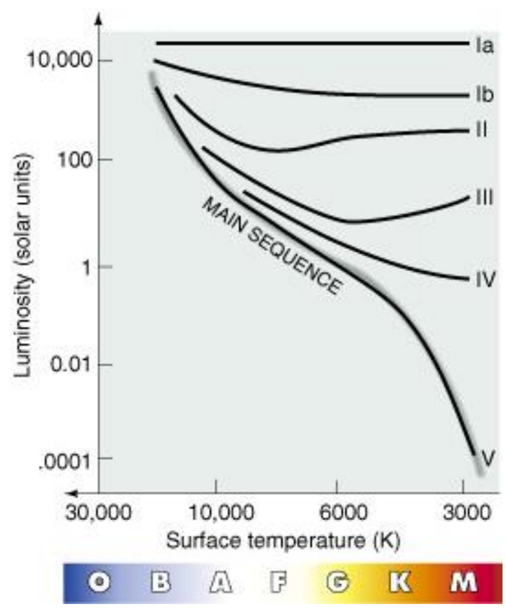
- The H-R Diagram is a plot of luminosity versus temperature for stars
  - Upon plotting all the known stars, there was a pattern that immediately emerged
  - A very large percentage of them fit into a clearly defined band that moved diagonally
- The Main Sequence
  - There are several patterns to the H-R Diagram
    - The Main Sequence is the band of stars that between 1 and 10 solar masses where most of the stars on the H-R Diagram fit.
    - The luminosity relationship to temperature and radius allows us to have a set of dashed lines indicating the solar radius across the chart as well.
- The White-Dwarf and Red-Giant Regions
  - The White Dwarf Region is the region of stars that are very small and very hot
  - The Red Dwarf Region is the region of stars that are very small and very cold
  - The Red Giant Region is the region of stars that are very large and very cold
  - The Blue Giant Region is the region of stars that are very large and very hot



10.6 Extending the Cosmic Scale

- Spectroscopic Parallax
  - For stars that are VERY far away, a process called spectroscopic parallax is used to determine the distances. It is based on relationships we know between quantities we can measure from far away.
    - Spectroscopic Parallax is a three step process to infer the distance of faraway objects
      - Step 1 = Measure the star's apparent brightness and spectral type *without* knowing how far away it is
      - Step 2 = Use spectral type to estimate the star's luminosity, assuming that it lies on the main sequence
      - Step 3 = Apply the inverse-square law to determine the distance to the star
- Luminosity Class
  - Objects that do not lie on the main sequence can be measured by their spectral line widths.
    - More dense objects have different width than less dense objects of the same material
  - Luminosity Class is the result of the system for classifying stars according to the width of their spectral lines

Class	Description
I	Supergiants
II	Bright giants
III	Giants
IV	Subgiants
V	Main-sequence stars



10.7 Stellar Masses

- Binary Stars
  - Binary-Star Systems are systems that involve 2 stars orbiting each other about their center of mass
    - Visual Binaries are binary star systems that have widely separated components bright enough for us to observe and monitor them separately.
    - Spectroscopic Binaries are too distant from us to be resolved into two distinct stars, but they can be determines using red/blue shifts of their spectral lines as they orbit each other
    - Eclipsing Binaries are binaries that orbit in the same plane of our sight and are detected by one star being blocked by the other as they orbit.
      - The Light Curve is the graph of variation of light from an eclipsing binary system. It is used to determine orbits, masses, and radii of the stars
- Mass Determination
  - Using a combination of measurements and mathematical relationships, the mass of almost all binaries visible to us have had their masses determined as well as the individual masses of each star within the binary system
- Mass and Other Stellar Properties
  - Mass, more than anything, determines the star's position on the main sequence.
    - Low mass stars are cool and faint
    - High mass stars are hot and bright

- Depending on the quantity needed and the quantities that are easily measurable, various theories are used to calculate the unknown quantity
- The lifetime of a star depends upon how much fuel it has to burn as well as how much energy it emits. The fuel that stars run on is mass, and the rate they burn fuel is related to their luminosity
  - The more mass a star has, the longer it can burn using nuclear fusion
  - The more luminosity the star has, the shorter it can burn because it emits more energy in the same amount of time as something that is less luminous
  - The equation for determining the stellar lifetime is:

$$stellar\ lifetime \propto \frac{stellar\ mass}{stellar\ luminosity}$$