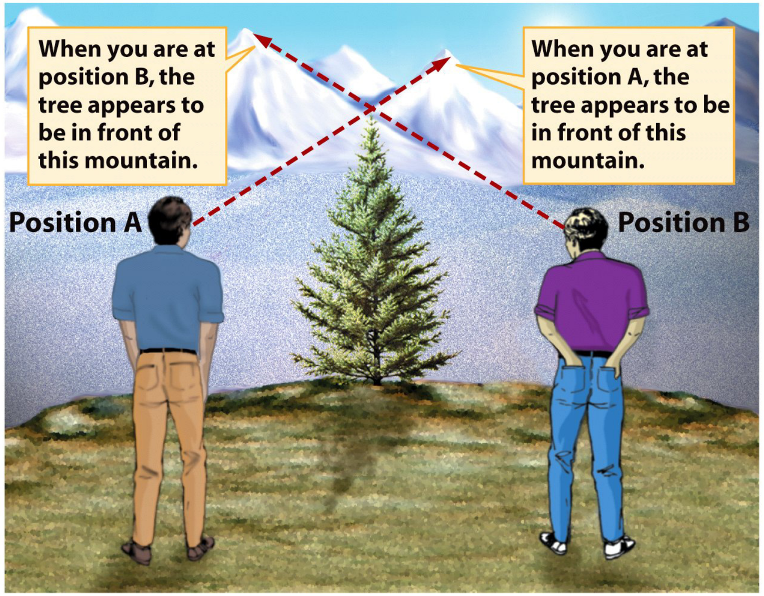
Measuring Stars

Guiding Questions

1. How far away are the stars?
2. What is meant by a "first-magnitude" or "second magnitude" star?
3. Why are some stars red and others blue?
4. What are the stars made of?
5. Is our Sun especially large or small?
6. What are giant, supergiant, and white dwarf stars?
7. How do we know the distances to really remote stars?

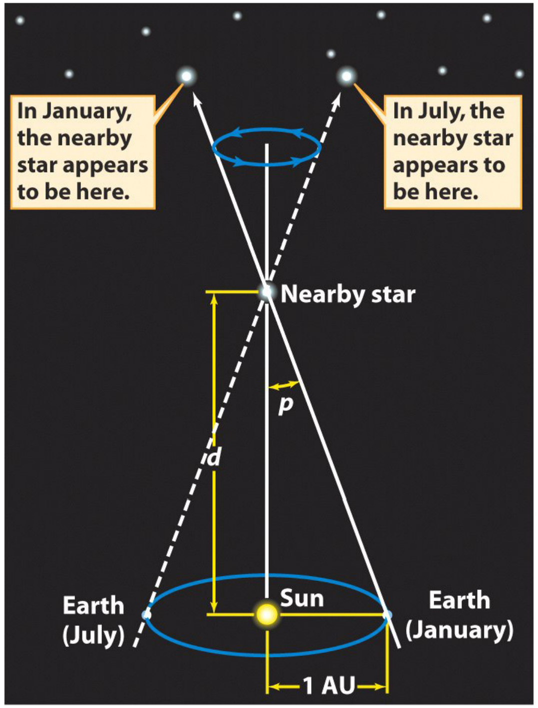
Preliminaries: Parallax

- The apparent displacement of a nearby object against a distant fixed background from two different viewpoints.



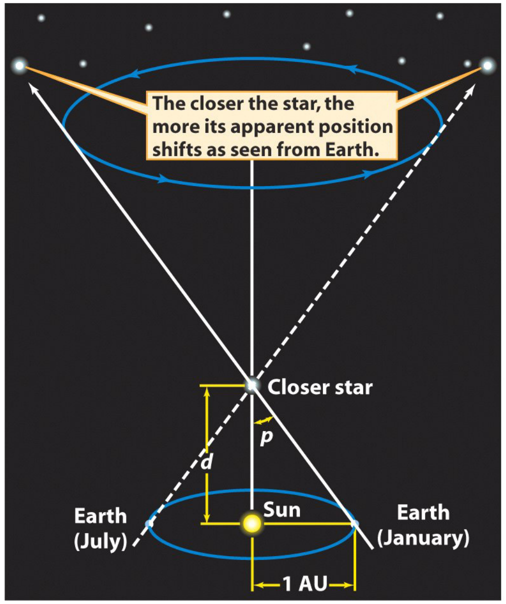
Stellar Parallax

The apparent position shift of a star as the Earth moves from one side of its orbit to the other (the largest separation of two viewpoints possibly from the Earth)



Parallax of a nearby star

Stellar Parallax



Parallax of an even closer star

Stellar Parallax and Distance

Relation between a star's distance and its parallax

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

d = distance to a star, in parsecs

p = parallax angle of that star, in arcseconds

1 pc = 3.26 ly

1 pc = 206,265 AU = 3.09 X 10^{13} km

Distances to the nearer stars can be determined by parallax, the apparent shift of a star against the background stars observed as the Earth moves along its orbit

Stellar Parallax

- **All known star have parallax angles less than one arcsec (1"), m**eaning their distance more than 1 parsec
- Stellar parallaxes can only be measured for stars within a few hundred parsecs
- The closest star Proxima Centauri has a parallax angle of 0.772 arcsec

  d=1/p => d=1/(0.772 arcsec) => d =1.30 pc

  d = 1.30 pc => d = 4.24 ly

  Therefore, the closest star is 4.24 light years away

Luminosity and Brightness

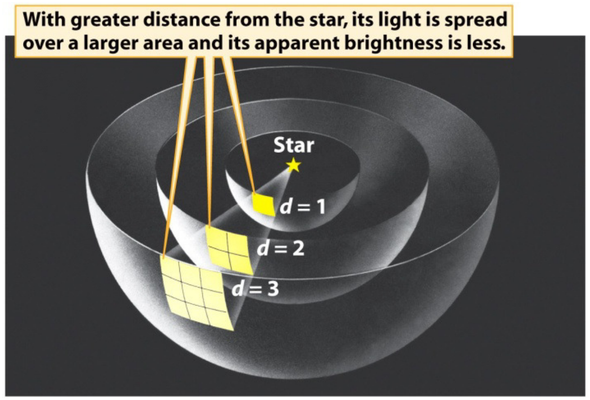
$$b = \frac{L}{4\pi d^2}$$

b = apparent brightness of a star's light, in W/m^2

L = star's luminosity, in W

d = distance to star, in meters

- A star's luminosity (total light output), apparent brightness, and distance from the Earth are related by the inverse-square law
- L can be calculated if d and b are measured.



Luminosity, Brightness and Distance

Determining a star's luminosity from its apparent brightness

$$\frac{L}{L_{\odot}} = \left(\frac{d}{d_{\odot}}\right)^2 \frac{b}{b_{\odot}}$$

$L/L_{\odot}$ = ratio of the star's luminosity to the Sun's luminosity

$d/d_{\odot}$ = ratio of the star's distance to the Earth-Sun distance

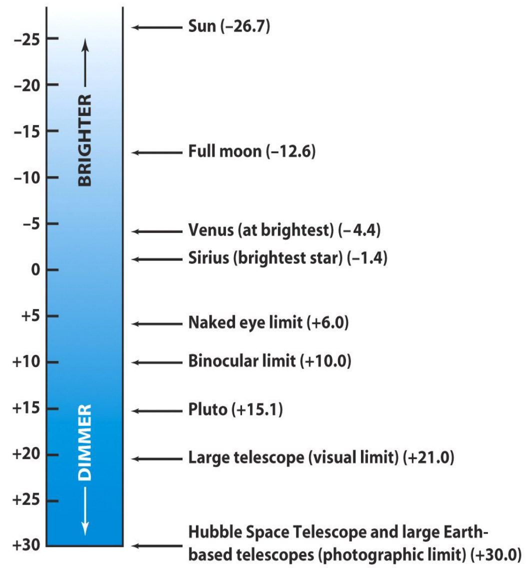
$b/b_{\odot}$ = ratio of the star's apparent brightness to the Sun's apparent brightness

- Many visible stars turn out to be more luminous than the Sun

Magnitude (Brightness) Scale

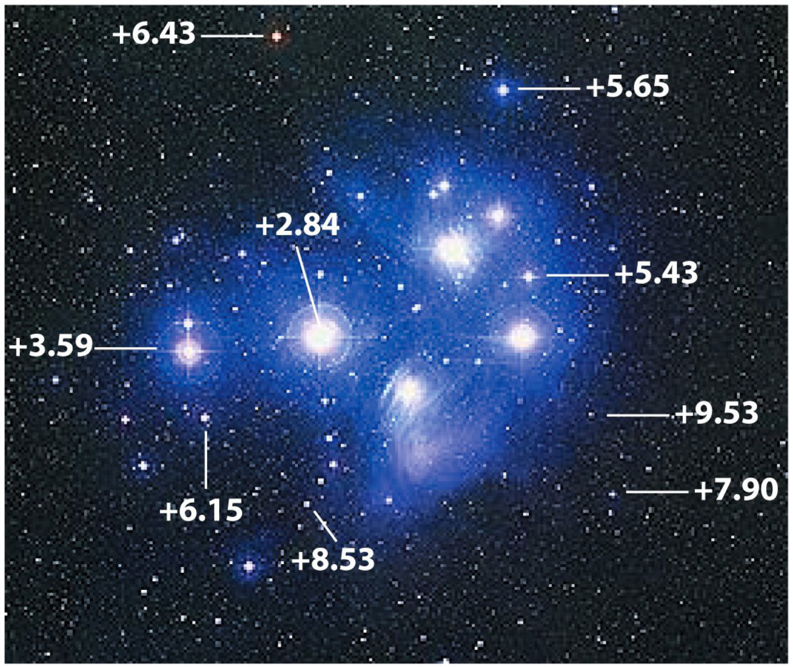
Apparent magnitude scale is a traditional way to denote a star's apparent brightness (~ 200 B.C. by Greek astronomer Hipparchus)

- First magnitude (brightest)
- Second magnitude, less bright
- Sixth magnitude, the dimmest one human naked eyes see



Some apparent magnitudes

Magnitude (Brightness) Scale



Apparent magnitudes of stars in the Pleiades

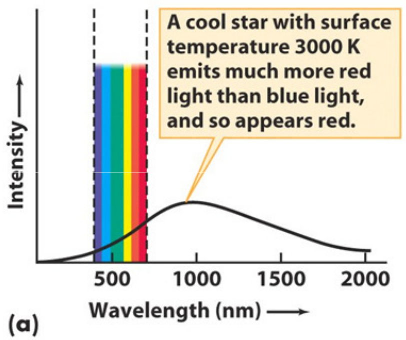
Apparent Magnitude and Absolute Magnitude

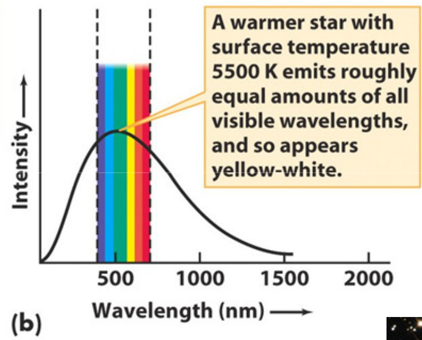
- **Apparent magnitude** is a measure of a star's apparent brightness as seen from Earth
  - the magnitude depends on the distance of the star
- **Absolute magnitude** is the apparent magnitude a star would have if it were located exactly 10 parsecs from Earth
  - This magnitude is independent of the distance
  - One way to denote the intrinsic luminosity of a star in the unit of magnitude
- The Sun's apparent magnitude is -26.7
- The Sun absolute magnitude is +4.8

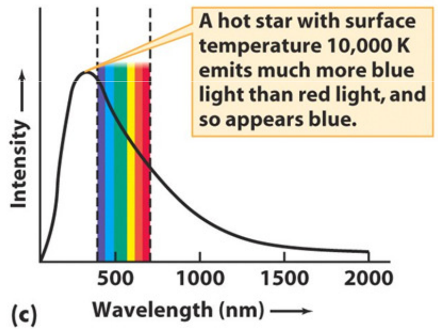
Mathematics of Scale of Magnitude

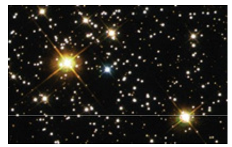
- The first magnitude star is 100 times brighter than the sixth magnitude star
- A magnitude difference of 1 corresponds to a factor of 2.512 in brightness
- Magnitude difference of 5 corresponds to a factor of 100 in brightness

A star's color depends on its surface temperature









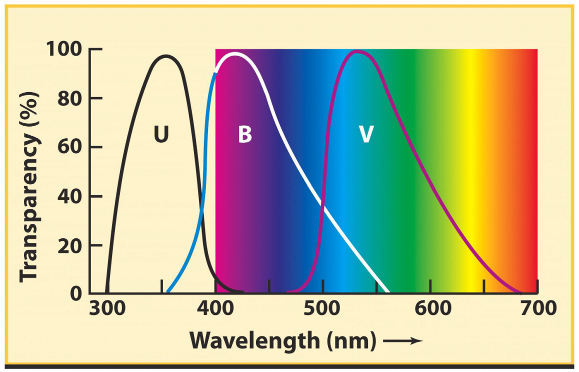
Wien's Law

$$\lambda_{max} = \frac{0.0029 \text{ K m}}{T}$$

λ_{max} = wavelength of maximum emission of the object (in meters)

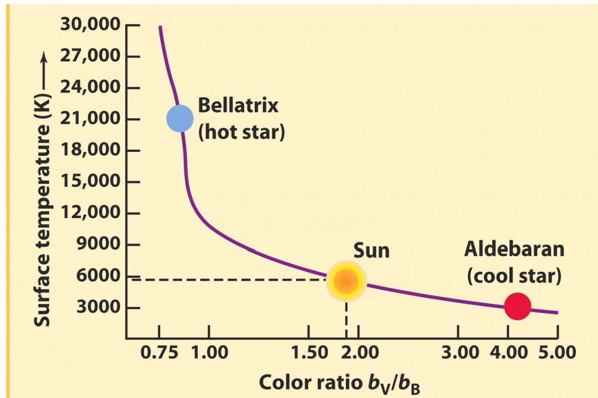
T = temperature of the object (in kelvins)

Surface Temperature Measurement



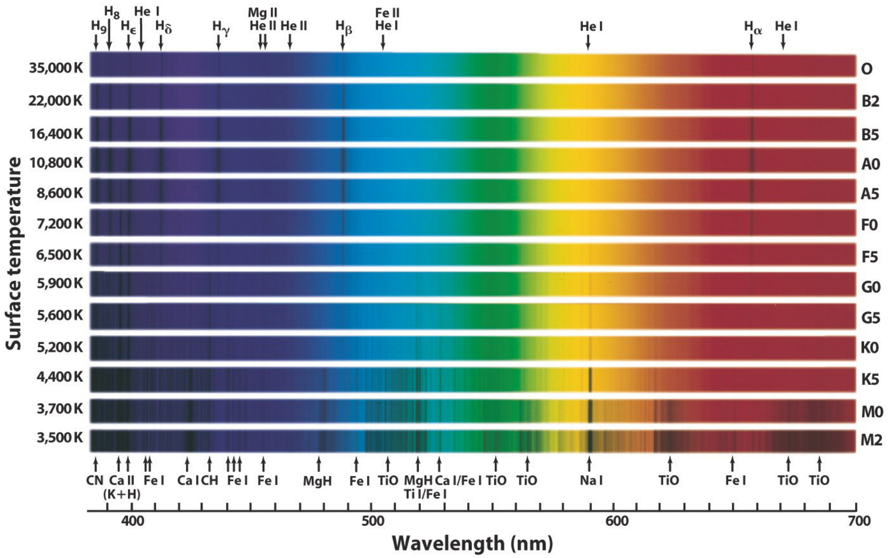
- **Photometry** measures the apparent brightness of a star
- **Standard filters**, such as U (Ultraviolet), B (Blue) and V (Visual, yellow-green) filters,
- **Color ratios** of a star are the ratios of brightness values obtained through different filters
- These ratios are a good measure of the star's **surface temperature;** this is an easy way to get temperature

Surface Temperature and Color Ratio



Star	Surface temperature (K)	b_V/b_B	b_B/b_U	Apparent color
Bellatrix (γ Orionis)	21,500	0.81	0.45	Blue
Regulus (α Leonis)	12,000	0.90	0.72	Blue-white
Sirius (α Canis Majoris)	9400	1.00	0.96	Blue-white
Megrez (δ Ursae Majoris)	8630	1.07	1.07	White
Altair (α Aquilae)	7800	1.23	1.08	Yellow-white
Sun	5800	1.87	1.17	Yellow-white
Aldebaran (α Tauri)	4000	4.12	5.76	Orange
Betelgeuse (α Orionis)	3500	5.55	6.66	Red

Stellar Spectrum and Temperature



- E.g., Balmer lines: Hydrogen lines of transition from higher orbits to n=2 orbit; Hα (orbit 3 -> 2) at 656 nm

Classic Spectral Types

- **O B A F G K M**
- Spectral type is directly related to tempature
- From O to M, the temperature decreases
- O type, the hottest, blue coror, Temp ~ 25000 K
- M type, the coolest, red color, Temp ~ 3000 K
- Sub-classes, e.g. B0, B1…B9, A0, A1…A9
- The Sun is a G2 type of star (temp. 5800 K)

Luminosity, Radius, and Surface Temperature

$$L = 4\pi R^2 \sigma T^4$$

L = star's luminosity, in watts
R = star's radius, in meters
σ = Stefan-Boltzmann constant = 5.67×10^{-8} W m^{-2} K^{-4}
T = star's surface temperature, in kelvins

- Reminder: Stefan-Boltzmann law states that a blackbody radiates electromagnetic waves with a total energy flux F directly proportional to the fourth power of the Kelvin temperature T of the object:

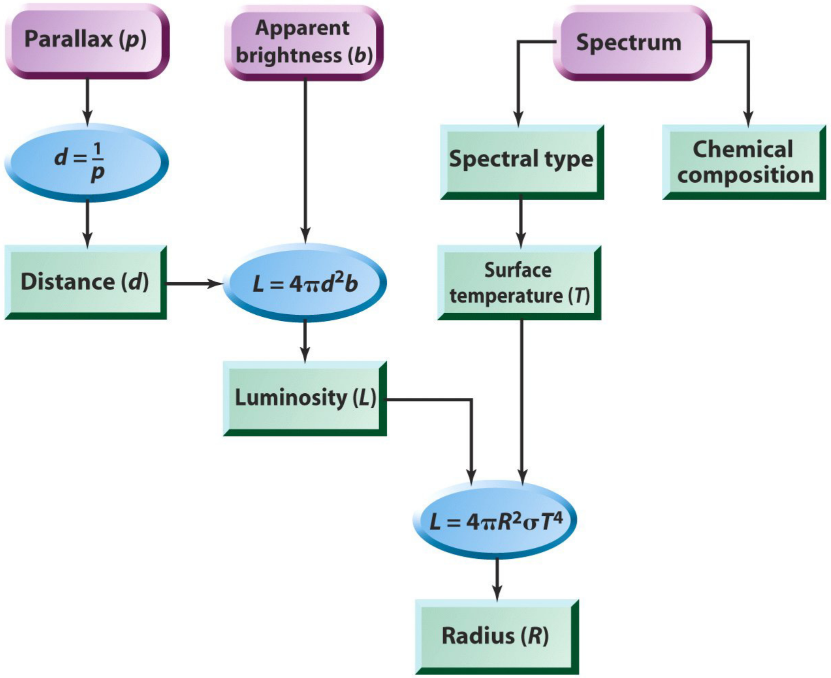
$$F = \sigma T^4$$

Luminosity, Radius, and Surface Temperature

- A more luminous star could be due to
  - Larger size (in radius)
  - Higher Surface Temperature
- Example: The first magnitude reddish star Betelgeuse is 60,000 time more luminous than the Sun and has a surface temperature of 3500 K, what is its radius (in unit of the solar radius)?

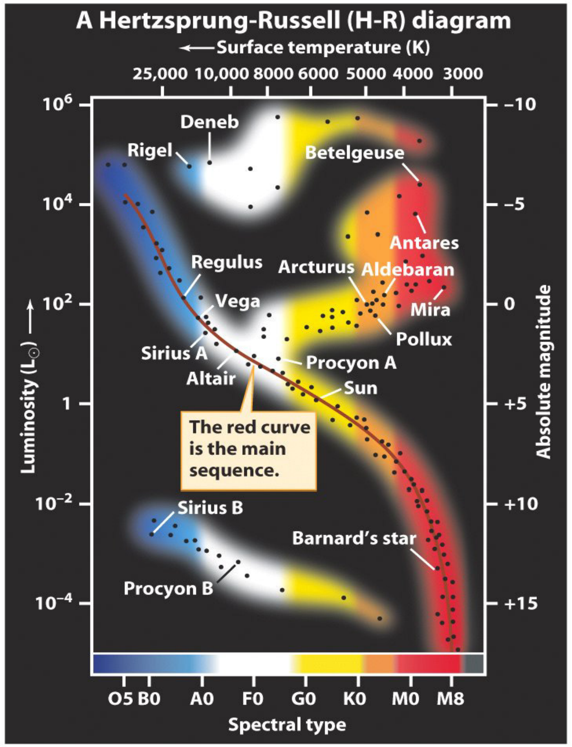
R = 670 Rs (radius of the Sun), A Supergiant star

Measuring the Radius



Hertzsprung-Russell (H-R) diagrams reveal the patterns of stars

The H-R diagram is a graph plotting the absolute magnitudes of stars against their spectral types—or, equivalently, their luminosities against surface temperatures



Hertzsprung-Russell (H-R) diagram

- Main Sequence
- Giants
  - upper- right side
  - Luminous (100 – 1000 Lsun)
  - Cool (3000 to 6000 K)
  - Large size (10 – 100 Rsun)
- Supergiants
  - Most upper-right side
  - Luminous (10000 - 100000 Lsun)
  - Cool (3000 to 6000 K)
  - Huge (1000 Rsun)
- White Dwarfs
  - Lower-middle
  - Dim (0.01 Ls)
  - Hot (10000 K)
  - Small (0.01 Rs)