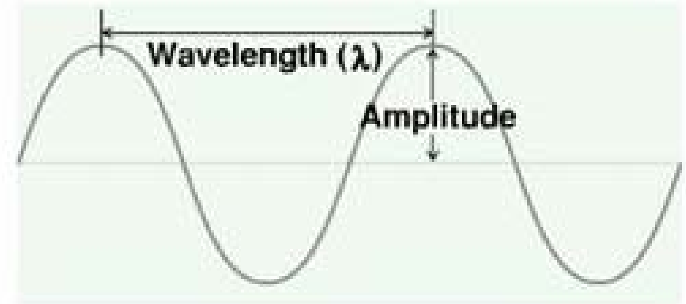
Analyzing Starlight

October 16, 2002

1) Blackbody radiation
2) Properties of Stars
3) Measuring the Properties of Stars
4) H-R diagram

Review



- Properties of waves
  - wavelength, frequency, period, speed
- Light is an electromagnetic wave
- Atoms/energy levels
  - absorption and emission of photons
- Doppler effect
- Temperature and light
  - all objects emit light
  - hotter = bluer & brighter

Temperature and Light

- Hot objects give off light
- Temperature is a measure of how fast the atoms/molecules are moving
  - hot atoms move faster than cooler atoms
    - faster movement means more collisions
- Collisions of atoms can convert energy to light
  - This is how an incandescent light bulb glows

Temperature and Light

- Hotter objects give off more light
  - luminosity is proportional to temperature raised to the fourth power

$$L \propto T^4$$

  - e.g. if you double an object's temperature, the luminosity goes up by a factor of 16 (2^4)
- Hotter objects give off bluer light
  - the wavelength is proportional to the inverse temperature

$$\lambda \propto 1/T$$

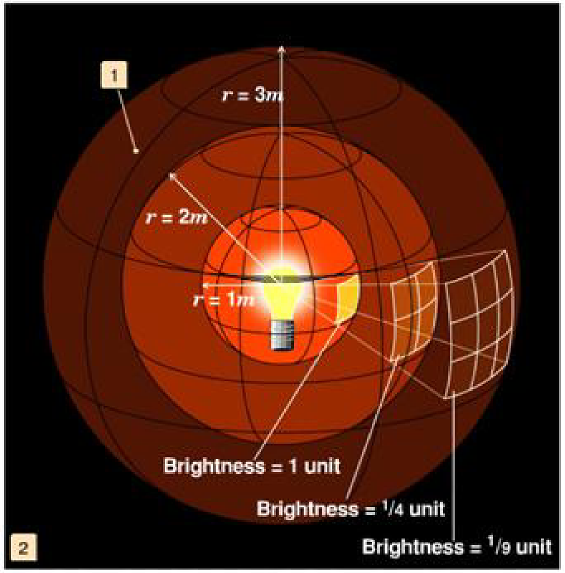
  - e.g. if you double an object's temperature, the wavelength drops in half

Intensity and Luminosity

- Luminosity is the total amount of light given off by an object
- Intensity is how much light we observe
  - if an object radiates light evenly in all directions…
  - the intensity goes as $1/r^2$ (r = distance from the source)

$$I = L/4\pi r^2$$

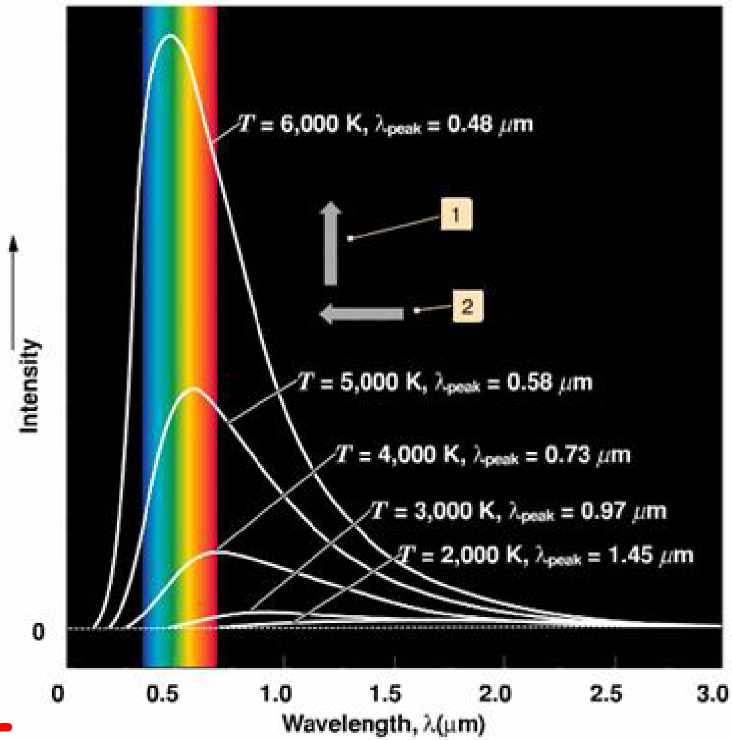
  - think of a sphere



- We can use the observed intensity to measure the distance if we know the luminosity

Blackbody Radiation

- Light radiated due to temperature, follows a pattern
  - blackbody radiation
  - all objects radiate light
- This can be used to measure the surface temperature of an object
  - this is how we can measure the temperature of the Sun



Temperature of the Sun

- We learned that $\lambda \propto 1/T$
- Really, it is λ = (2900 μm K)/T

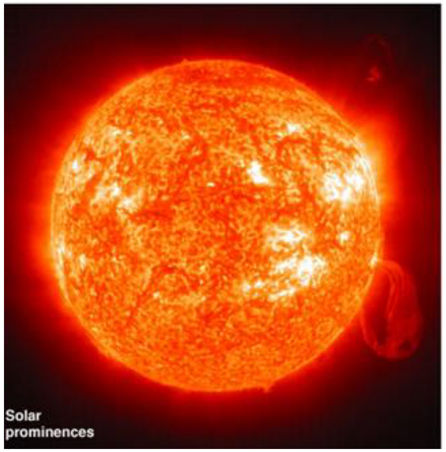
  we can rewrite as T = (2900 μm K)/λ
  - μm = micron = 1×10^{-6} m
  - K = Kelvin (a measure of temperature
    - K = 0 is absolute zero, the coldest temperature possible
    - K = 273 is the freezing point of water (32 °F)
    - K = 373 is the boiling point of water (212 °F)
  - the Sun's light peaks at λ = 0.5 μm
- So, T = (2900 μm K)/0.5 μm = 5,800 K
- So the surface temperature of the Sun is 5,800 K

Sources of Light

- Several primary sources of light
  - reflection of light from another source
    - how we see most objects in this room
    - how we see planets, the Moon, asteroids, etc
  - creation of light from energy
    - glow of hot materials or from fusion
    - how the Sun glows
    - how we see comets
  - atomic emission of photons
    - could be from absorption
    - how we identify gases on a remote body

Observing Stars

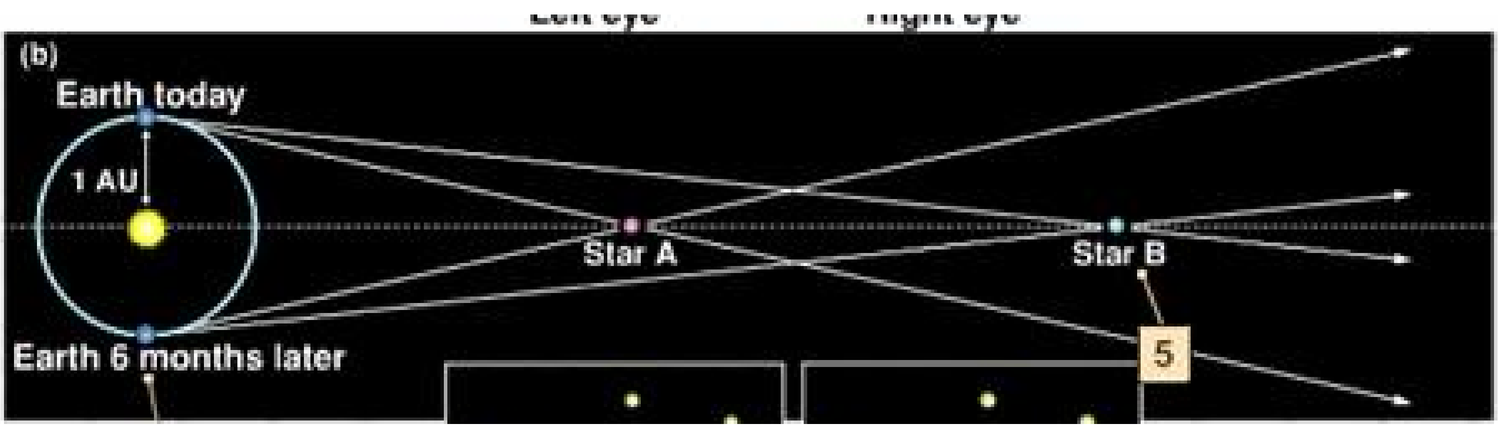
- We study stars by observing their light
- What can we learn about stars?
  - Brightness/luminosity
  - Distance from us
  - Velocity (has fast/what direction)
  - Mass
  - Size
  - Composition



- Ultimately, we would like to find common characteristics between stars and learn the how and why of them

Stereoscopic Viewing

- To determine distance to an object, we view it from 2 different places
  - see how it moves with respect to far background
  - this is how our eyes work
- In astronomy, we view stars from different parts of the Sun's orbit
  - close stars will move a lot, far stars will move a little

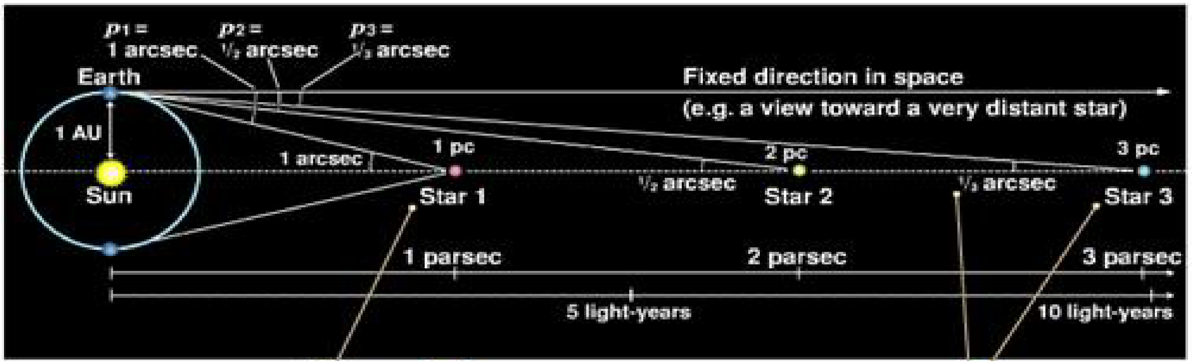


Measuring Distance

- By measuring the angle by which the star "moves", we can determine the distance

$$\text{distance(parsecs)} = \frac{1}{\text{angle(arcsecs)}}$$

- Angles
  - 1 degree = 60 arcminutes
  - 1 arcminute = 60 arcseconds
  - 1 arcsecond = 1/360th degree
- Distance
  - 1 parsec = 3.26 lightyears



Measuring Luminosity

- We measure a star's brightness by how much light we see
- We have just measured its distance
- Therefore, we can measure luminosity

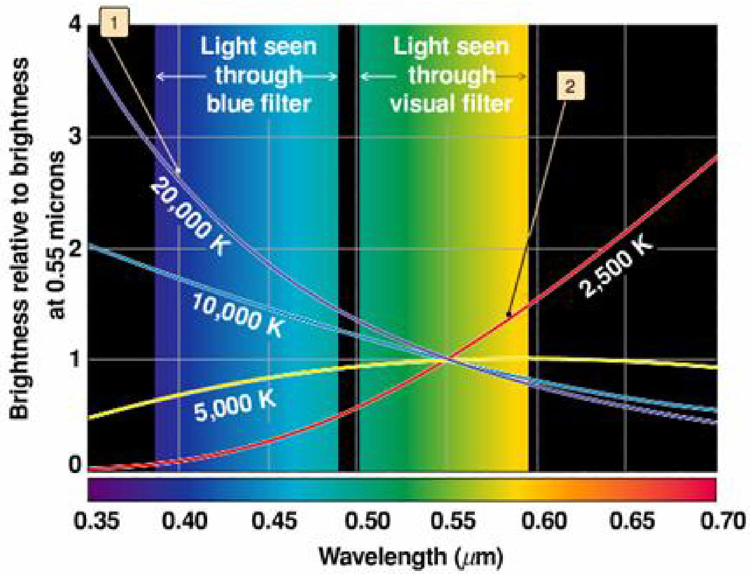
  brightness = luminosity/$4\pi r^2$ (r = distance to star)

  luminosity = brightness x $4\pi r^2$

- We have measured the luminosity of many nearby stars
  - Our Sun is more luminous than most
  - Least luminous is 0.0001 times our Sun
  - Most luminous is 10^6 times our Sun

Measuring Temperature

- We use the colors of light to determine temperature
  - measure light through a blue filter and a yellow-green filter
  - ratio of amount of light allows us to measure the temperature
    - like we did for the Sun
  - most stars are cooler than our Sun



Measuring Size

- Once we know the luminosity and temperature, we can measure the size

$$\text{luminosity} = \text{surface area} \times \text{constant} \times T^4$$

$$\text{surface area} = 4\pi r^2 \ (r = \text{radius of star})$$

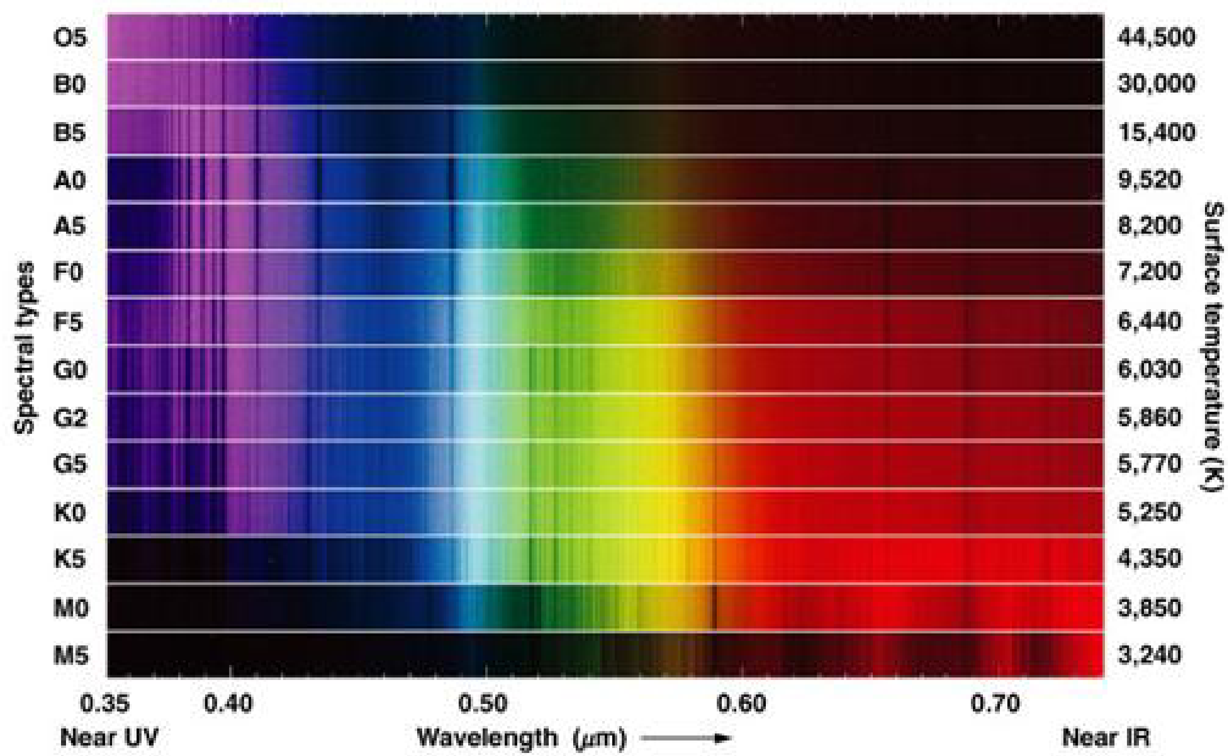
$$\text{luminosity} = 4\,\pi r^2 \times \text{constant} \times T^4$$

  - we can solve for radius and calculate it
- Most stars are smaller than the Sun
- Smallest stars are 0.01 times the size of the Sun
- Largest stars at several thousand times the size of the Sun

Classification of Stars

- Classify stars by temperature
- Classes: O, B, A, F, G, K, M
  - Oh, Be A Fine Guy/Gal, Kiss Me

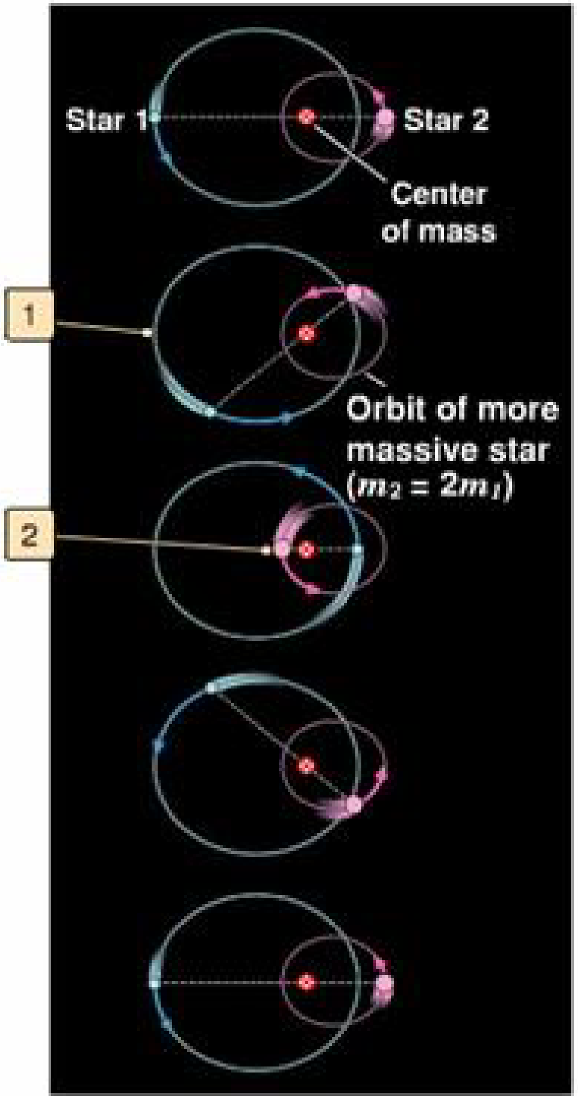
- O is the hottest stars
- M are the coolest stars
- The Sun is a G class



Determining the Mass

- Determine the mass from the effects of gravity
- Use binary star systems
  - two stars orbiting each other
  - they follow ellipses with a shared focal point (Kepler's Laws)
  - measure velocities
- Visual measurement
  - see both stars, use Doppler shift
- Eclipsing binary
  - one passes in from of the other

` and brightness changes



Stellar Composition

- Stars are primarily composed of hydrogen and helium
  - some other trace elements
- Here's a sampling of composition

Element	Percent by Number	Percent by Mass
Hydrogen	92.5%	74.5% .
Helium	7.4%	23.7% .
Oxygen	0.064%	0.82%
Carbon	0.039%	0.37%
Neon	0.012%	0.19%
Nitrogen	0.008%	0.09%
Iron	0.003%	0.13%

H-R Diagram

- Einar Hertzsprung
- Henry Russell
- Compiled data on stars
- Plotted luminosity vs temperature
- Astronomers consider this the most important plot