Astronomy 114

Lecture 16: Properties of Stars (Part 2)

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UMass/Astronomy Department
Announcements

- PS #4 posted; due this Friday (before Spring break)
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- Quiz #1 redux due Wednesday
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Today:
- Properties of Stars (Part 2)
- *The Nature of Stars, Chap. 19*
- *The Birth of Stars, Chap. 20*
Last lecture . . .

- Distances to stars: parallax
- Distances to stars: using brightness (photometric distance)
- Magnitude scale
- Colors of stars
Inferring the size of stars (1/2)

- Use UBV photometry or spectral class to estimate temperature

- Recall: \( L = 4\pi R^2 \sigma T^4 \)

- For Sun: \( L_\odot = 4\pi R_\odot^2 \sigma T_\odot^4 \)

- Ratio:

\[
\left( \frac{L}{L_\odot} \right) = \left( \frac{R}{R_\odot} \right)^2 \left( \frac{T}{T_\odot} \right)^4
\]

- Solve for radius:

\[
\frac{R}{R_\odot} = \left( \frac{T}{T_\odot} \right)^{-2} \sqrt{\frac{L}{L_\odot}}
\]
Inferring the size of stars (2/2)

Example: Betelgeuse

- \( L = 60,000 \) \( (L_\odot = 6 \times 10^4 L_\odot) \)
- \( T = 3500K \) \( (T_\odot = 5800K) \)
- Ratio of radii:

\[
\frac{R}{R_\odot} = \left(\frac{3500}{5800}\right)^{-2} \sqrt{6 \times 10^4} = 6.7 \times 10^2 = 670
\]
Inferring the size of stars (2/2)

Example: Betelgeuse

- $L = 60,000 \ (L_\odot = 6 \times 10^4 L_\odot)$
- $T = 3500K \ (T_\odot = 5800K)$
- **Ratio of radii:**

$$\frac{R}{R_\odot} = \left(\frac{3500}{5800}\right)^{-2} \sqrt{6 \times 10^4} = 6.7 \times 10^2 = 670$$

- $R_\odot = 6.96 \times 10^5 km$
- $1 AU = 1.5 \times 10^8 km$
- $R = 670 \times 6.96 \times 10^5 km = 4.7 \times 10^8 km = 3.1 AU$
Hertzsprung-Russell (HR) diagram

How to understand all of these data?

- Plot absolute magnitude vs color
- Plot absolute luminosity vs temperature
- Stars cover only small regions!
Hertzsprung-Russell (HR) diagram

How to understand all of these data?

- Plot absolute magnitude vs color
- Plot absolute luminosity vs temperature
- Stars cover only small regions!
- Add radius relationship:

\[
\frac{R}{R_\odot} = \left(\frac{T}{T_\odot}\right)^{-2}\sqrt{\frac{L}{L_\odot}}
\]
Luminosity classes (1/2)

- Stars divided into 5 (I–V) luminosity classes
- Classes are empirical
- Not understood until mid 20th century
Luminosity classes (2/2)

Stars with smaller radii have higher pressure at their photosphere

*Buffeting* of atoms causes absorption lines to be broadened

Can distinguish luminosity class
Given well-calibrated main sequence, can get distances to distant star clusters

Pleiades star cluster
Distances to star clusters (2/2)

Globular star cluster (M15)
Distances to star clusters (2/2)

Globular star cluster (M15)

\[ L_{\text{obs}} = L_0 \left( \frac{d_0}{d} \right)^2 \]
Distances to star clusters (2/2)

Globular star cluster (M15)

- \( L_{\text{obs}} = L_0 \left( \frac{d_0}{d} \right)^2 \)
- \( \log(L_{\text{obs}}) = \log(L_0) + \log(d_0/d)^2 \)
- Shift in luminosity scale!!
Masses of stars (1/2)

- No way of weighing isolated star (besides Sun)
- More than 50% of all stars are binary stars
- Binary star: pair of stars that are gravitationally bound
- Orbit around common center of mass

![Diagram of a binary star system]

A114: Lecture 16—12 Mar 2007
Read: Ch. 19,20
Astronomy 114—11/18
Masses of stars (2/2)

Use Newton’s version of Kepler’s 3rd Law

\[ M_1 + M_2 = \frac{4\pi^2 a^3}{GP^2} \]
Masses of stars (2/2)

Use Newton’s version of Kepler’s 3rd Law

\[ M_1 + M_2 = \frac{4\pi^2}{G} \frac{a^3}{P^2} \]

Procedure:
1. Measure the period, \( P \), by tracing the orbit on the sky.
2. Measure semi-major axis, \( a \), and mass ratio, \( M_1/M_2 \), from the projected orbit on the sky.
3. Solve the equation above.
Masses of stars (2/2)

Use Newton’s version of Kepler’s 3rd Law

\[ M_1 + M_2 = \frac{4\pi^2}{G} \frac{a^3}{P^2} \]

Procedure:
1. Measure the period, \( P \), by tracing the orbit on sky
2. Measure semi-major axis, \( a \), and mass ratio, \( \frac{M_1}{M_2} \), from the projected orbit on the sky
3. Solve the equation above

Need to follow large fraction of orbital period
- Can take decades
- Need to work out the projection on the sky
Spectroscopic binaries (1/2)

- Most binaries too far away to resolve separate stars
- But, can detect their orbital motions by the periodic Doppler shifts of the spectral lines
- Determine orbit period & size from pattern of orbital velocities

[diagram of spectroscopic binaries with stages 1 to 4, showing the motion of stars A and B relative to the center of mass and their spectral lines]
Spectroscopic binaries (2/2)

Limitations:
- Semi-major axis must be fit from orbital motion
- Can not determine projection (tilt) against the sky
- Need to estimate distance independently
Eclipsing binaries (1/2)

- Two stars orbiting nearly edge-on to our line-of-sight.
  1. Periodic drop in brightness from eclipse
  2. Combine with spectra to measure orbital speeds
- Can find the masses of the stars without distance!
- Best masses are from eclipsing binaries.
Limitations:

- Eclipsing Binary stars are very rare
- Measurement of the light curves is complicated by details
  - Partial eclipses yield less accurate numbers
  - The atmospheres of the stars soften the edges
  - Close binaries can be tidally distorted
- (See textbook for light curves...)

Eclipsing binaries (2/2)
Mass-luminosity relationship

- Main sequence stars
- Low-mass stars are faint
- High-mass stars are bright
- Main sequence relationship is *tight*
  Implies some physics is causing this!
Mass-luminosity-color relationship

- **Main sequence stars**
- **Faint low-mass stars are red**
- **Bright high-mass stars are blue**