Chapter 15
Surveying the Stars

15.1 Properties of Stars

Our goals for learning:

- How do we measure stellar luminosities?
- How do we measure stellar temperatures?
- How do we measure stellar masses?

Luminosity:

Amount of power a star radiates

(energy per second = watts)

Apparent brightness:

Amount of starlight that reaches Earth

(energy per second per square meter)

Luminosity passing through each sphere is the same

Area of sphere:

$4\pi\ (\text{radius})^2$

Divide luminosity by area to get brightness

The relationship between apparent brightness and luminosity depends on distance:

$$\text{Brightness} = \frac{\text{Luminosity}}{4\pi\ (\text{distance})^2}$$

We can determine a star's luminosity if we can measure its distance and apparent brightness:

$$\text{Luminosity} = 4\pi\ (\text{distance})^2 \times (\text{Brightness})$$

Parallax is the apparent shift in position of a nearby object against a background of more distant objects

Apparent positions of nearest stars shift by about an arcsecond as Earth orbits Sun

Parallax and Distance

p = parallax angle

$$d \text{ (in parsecs)} = \frac{1}{p \text{ (in arcseconds)}}$$

$$d \text{ (in light-years)} = 3.26 \times \frac{1}{p \text{ (in arcseconds)}}$$

Most luminous stars:

10^6 L_{Sun}

Least luminous stars:

10^{-4} L_{Sun}

(L_{Sun} is luminosity of Sun)

The Magnitude Scale

m = apparent magnitude , M = absolute magnitude

$$\frac{\text{apparent brightness of Star 1}}{\text{apparent brightness of Star 2}} = (100^{1/5})^{m_1 - m_2}$$

$$\frac{\text{luminosity of Star 1}}{\text{luminosity of Star 2}} = (100^{1/5})^{M_1 - M_2}$$

Properties of Thermal Radiation

1. Hotter objects emit more light per unit area at all frequencies.
2. Hotter objects emit photons with a higher average energy.

Hottest stars:

50,000 K

Coolest stars:

3,000 K

(Sun's surface is 5,800 K)

Level of ionization also reveals a star's temperature

Remembering Spectral Types

(Hottest) O B A F G K M (Coolest)

- Oh, Be A Fine Girl, Kiss Me
- Only Boys Accepting Feminism Get Kissed Meaningfully

Pioneers of Stellar Classification

- Annie Jump Cannon and the "calculators" at Harvard laid the foundation of modern stellar classification

Types of Binary Star Systems

- Visual Binary
- Eclipsing Binary
- Spectroscopic Binary

About half of all stars are in binary systems

Visual Binary

We can directly observe the orbital motions of these stars

Eclipsing Binary

We can measure periodic eclipses

Spectroscopic Binary

We determine the orbit by measuring Doppler shifts

We measure mass using gravity

Direct mass measurements are possible only for stars in binary star systems

$$p^2 = \frac{4\pi^2}{G\,(M_1 + M_2)}\,a^3$$

p = period

a = average separation

Need 2 out of 3 observables to measure mass:

1) Orbital Period (p)
2) Orbital Separation (a or r = radius)
3) Orbital Velocity (v)

For circular orbits, $v = 2\pi r / p$

Most massive stars:

100 M_{Sun}

Least massive stars:

0.08 M_{sun}

(M_{Sun} is the mass of the Sun)

What have we learned?

- How do we measure stellar luminosities?
  - If we measure a star's apparent brightness and distance, we can compute its luminosity with the inverse square law for light
  - Parallax tells us distances to the nearest stars
- How do we measure stellar temperatures?
  - A star's color and spectral type both reflect its temperature

What have we learned?

- How do we measure stellar masses?
  - Newton's version of Kepler's third law tells us the total mass of a binary system, if we can measure the orbital period (*p*) and average orbital separation of the system (*a*)

15.2 Patterns Among Stars

Our goals for learning:

- What is a Hertzsprung-Russell diagram?
- What is the significance of the main sequence?
- What are giants, supergiants, and white dwarfs?
- Why do the properties of some stars vary?

Luminosity

Temperature

An H-R diagram plots the luminosity and temperature of stars

Main Sequence

Most stars fall somewhere on the ***main sequence*** of the H-R diagram

Large radius

Main Sequence

Stars with lower T and higher L than main-sequence stars must have larger radii:

giants and ***supergiants***

Main Sequence

Small radius

Stars with higher T and lower L than main-sequence stars must have smaller radii:

white dwarfs

A star's full classification includes spectral type (line identities) and luminosity class (line shapes, related to the size of the star):

- I - supergiant
- II - bright giant
- III - giant
- IV - subgiant
- V - main sequence

Examples:
- Sun - G2 V
- Sirius - A1 V
- Proxima Centauri - M5.5 V
- Betelgeuse - M2 I

Luminosity

H-R diagram depicts:

- Temperature
- Color
- Spectral Type
- Luminosity
- Radius

Temperature

Main-sequence stars are fusing hydrogen into helium in their cores like the Sun

Luminous main-sequence stars are hot (blue)

Less luminous ones are cooler (yellow or red)

High-mass stars

Low-mass stars

Mass measurements of main-sequence stars show that the hot, blue stars are much more massive than the cool, red ones

High-mass stars

The mass of a normal, hydrogen-burning star determines its luminosity and spectral type!

Low-mass stars

Core pressure and temperature of a higher-mass star need to be larger in order to balance gravity

Higher core temperature boosts fusion rate, leading to larger luminosity

Stellar Properties Review

Luminosity: from brightness and distance
($0.08\ M_{Sun}$) $10^{-4}\ L_{Sun}$ - $10^{6}\ L_{Sun}$ ($100\ M_{Sun}$)

Temperature: from color and spectral type
($0.08\ M_{Sun}$) 3,000 K - 50,000 K ($100\ M_{Sun}$)

Mass: from period (p) and average separation (a) of binary-star orbit
$0.08\ M_{Sun}$ - $100\ M_{Sun}$

Mass & Lifetime

Until core hydrogen (10% of total) is used up

Sun's life expectancy: 10 billion years

Life expectancy of 10 M_{Sun} star:

10 times as much fuel, uses it 10^4 times as fast

10 million years ~ 10 billion years x 10 / 10^4

Life expectancy of 0.1 M_{Sun} star:

0.1 times as much fuel, uses it 0.01 times as fast

Main-Sequence Star Summary

High Mass:
- High Luminosity
- Short-Lived
- Large Radius
- Blue

Low Mass:
- Low Luminosity
- Long-Lived
- Small Radius
- Red

Off the Main Sequence

- Stellar properties depend on both mass and age: those that have finished fusing H to He in their cores are no longer on the main sequence
- All stars become larger and redder after exhausting their core hydrogen: **giants** and **supergiants**
- Most stars end up small and white after fusion has ceased: **white dwarfs**

Variable Stars

- Any star that varies significantly in brightness with time is called a *variable star*
- Some stars vary in brightness because they cannot achieve proper balance between power welling up from the core and power radiated from the surface
- Such a star alternately expands and contracts, varying in brightness as it tries to find a balance

Pulsating Variable Stars

- The light curve of this *pulsating variable star* shows that its brightness alternately rises and falls over a 50-day period

Cepheid Variable Stars

- Most pulsating variable stars inhabit an *instability strip* on the H-R diagram
- The most luminous ones are known as *Cepheid variables*

What have we learned?

- What is a Hertzsprung-Russell diagram?
  - An H-R diagram plots stellar luminosity of stars versus surface temperature (or color or spectral type)
- What is the significance of the main sequence?
  - Normal stars that fuse H to He in their cores fall on the main sequence of an H-R diagram
  - A star's mass determines its position along the main sequence (high-mass: luminous and blue; low-mass: faint and red)

What have we learned?

- What are giants, supergiants, and white dwarfs?
  - All stars become larger and redder after core hydrogen burning is exhausted: **giants** and **supergiants**
  - Most stars end up as tiny **white dwarfs** after fusion has ceased
- Why do the properties of some stars vary?
  - Some stars fail to achieve balance between power generated in the core and power radiated from the surface

15.3 Star Clusters

Our goals for learning:

- What are the two types of star clusters?
- How do we measure the age of a star cluster?

Open cluster: A few thousand loosely packed stars

Globular cluster: Up to a million or more stars in a dense ball bound together by gravity

Massive blue stars die first, followed by white, yellow, orange, and red stars

Pleiades now has no stars with life expectancy less than around 100 million years

Main-sequence turnoff

Main-sequence turnoff point of a cluster tells us its age

To determine accurate ages, we compare models of stellar evolution to the cluster data

Detailed modeling of the oldest globular clusters reveals that they are about 13 billion years old

What have we learned?

- What are the two types of star clusters?
  - Open clusters are loosely packed and contain up to a few thousand stars
  - Globular clusters are densely packed and contain hundreds of thousands of stars
- How do we measure the age of a star cluster?
  - A star cluster’s age roughly equals the life expectancy of its most massive stars still on the main sequence