

Chapter 15

Surveying the Stars

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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?

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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)

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Luminosity passing through each sphere is the same

Area of sphere:

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

Divide luminosity by area to get brightness

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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:

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

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Parallax

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

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

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Parallax and Distance

p = parallax angle

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

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

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Most luminous stars:

$$10^6 L_{\text{Sun}}$$

Least luminous stars:

$$10^{-4} L_{\text{Sun}}$$

(L_{Sun} is luminosity of Sun)

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The Magnitude Scale

m = apparent magnitude , M = absolute magnitude

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

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

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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.

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Hottest stars:

50,000 K

Coollest stars:

3,000 K

(Sun's surface
is 5,800 K)

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Level of ionization
also reveals a star's
temperature

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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

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Pioneers of Stellar Classification

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

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Types of Binary Star Systems

- Visual Binary
- Eclipsing Binary
- Spectroscopic Binary

About half of all stars are in binary systems

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Visual Binary

We can directly observe the orbital motions of these stars

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Eclipsing Binary

We can measure periodic eclipses

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Spectroscopic Binary

We determine the orbit by measuring Doppler shifts

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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

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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, $v = 2\pi r / p$

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Most massive stars:

$$100 M_{\text{Sun}}$$

Least massive stars:

$$0.08 M_{\text{Sun}}$$

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

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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

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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)

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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?

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Luminosity ↑

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

← Temperature

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Main Sequence

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

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Large radius

Main Sequence

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

giants and ***supergiants***

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Main Sequence

Small radius

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

white dwarfs

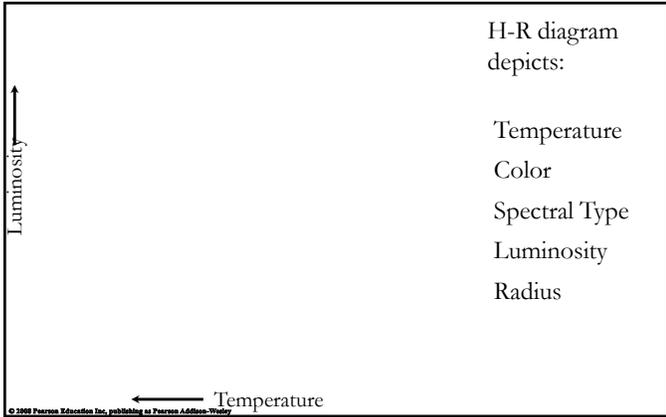
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A star's full classification includes spectral type (line identities) and luminosity class (line shapes, related to the size of the star):

- 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

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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)

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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

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High-mass stars

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

Low-mass stars

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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

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Stellar Properties Review

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

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

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

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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 $\times 10 / 10^4$

Life expectancy of 0.1 M_{Sun} star:

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

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Main-Sequence Star Summary

High Mass:
High Luminosity
Short-Lived
Large Radius
Blue
Low Mass:
Low Luminosity
Long-Lived
Small Radius
Red

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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**

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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

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Pulsating Variable Stars

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

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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*

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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)

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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

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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?

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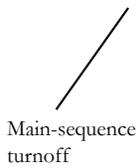
Open cluster: A few thousand loosely packed stars

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

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

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

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

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

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

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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

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