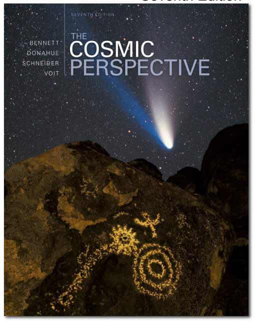
Chapter 15 Lecture

The Cosmic Perspective

Seventh Edition



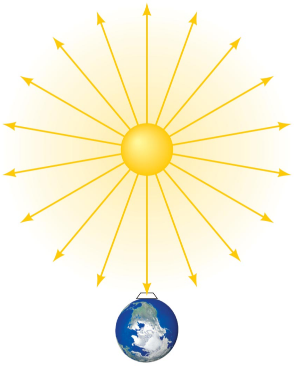
Surveying the Stars

Surveying the Stars

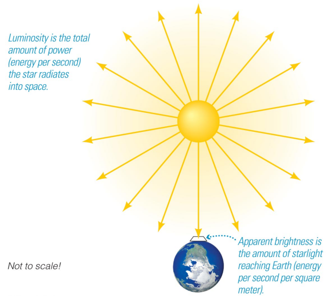
15.1 Properties of Stars

- Our goals for learning:
  - **How do we measure stellar luminosities?**
  - **How do we measure stellar temperatures?**
  - **How do we measure stellar masses?**

How do we measure stellar luminosities?



- The brightness of a star depends on both distance and luminosity.



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)

Thought Question

Alpha Centauri and the Sun have about the same luminosity. Which one appears brighter?

A. Alpha Centauri
B. The Sun

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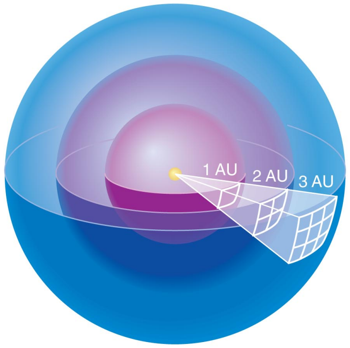

- The amount of luminosity passing through each sphere is the same.

  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:

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

Thought Question

How would the apparent brightness of Alpha Centauri change if it were three times farther away?

A. It would be only 1/3 as bright
B. It would be only 1/6 as bright.
C. It would be only 1/9 as bright.
D. It would be three times brighter.

Thought Question

How would the apparent brightness of Alpha Centauri change if it were three times farther away?

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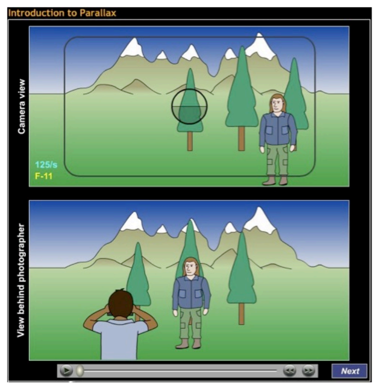
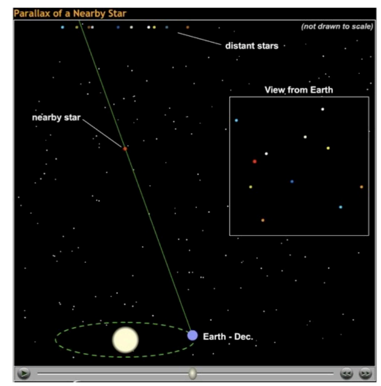
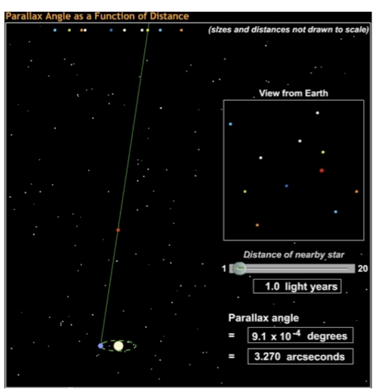
- So how far away are these stars?



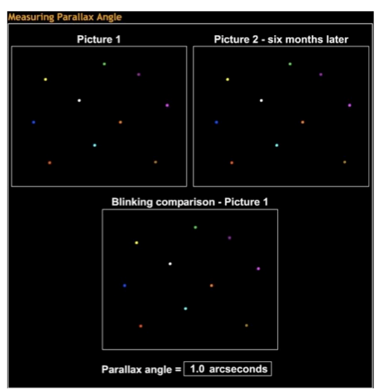
- ***Parallax*** is the apparent shift in position of a nearby object against a background of more distant objects.



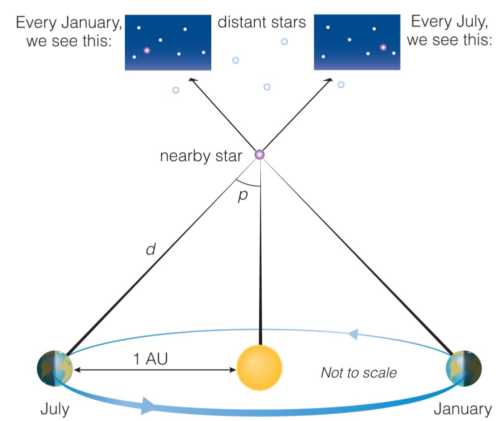
- Apparent positions of nearest stars shift by about an arcsecond as Earth orbits Sun.



- Parallax angle depends on distance.



- Parallax is measured by comparing snapshots taken at different times and measuring the shift in angle to star.

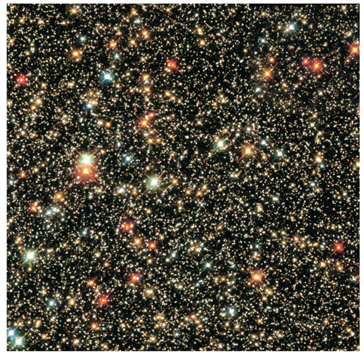


Parallax and Distance

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)

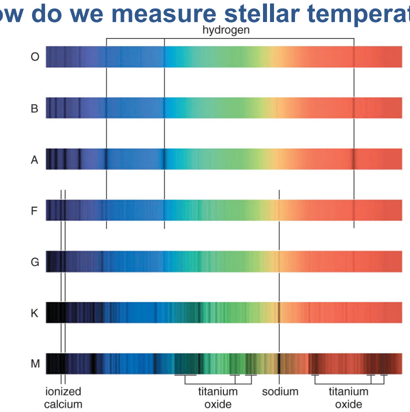
The Magnitude Scale

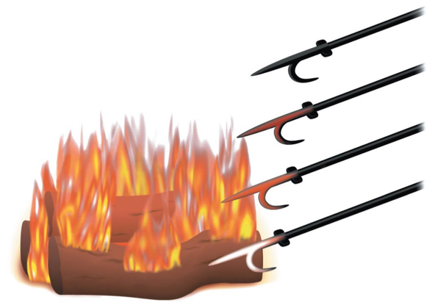
m = apparent magnitude, M = absolute magnitude

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

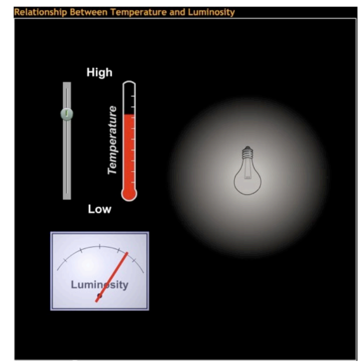
$$\frac{\text{Luminosity of star 1}}{\text{Luminosity of star 2}} = (100^{1/5})^{M_1 - M_2}$$

How do we measure stellar temperatures?





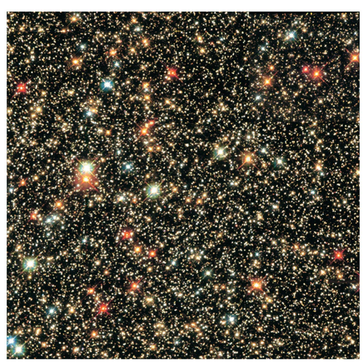
- Every object emits ***thermal radiation*** with a spectrum that depends on its temperature.



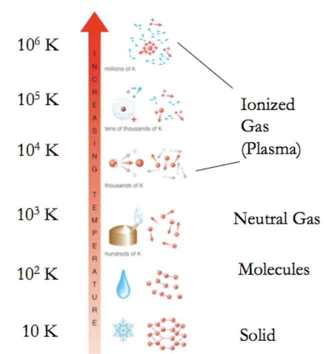
- An object of fixed size grows more luminous as its temperature rises.

Properties of Thermal Radiation

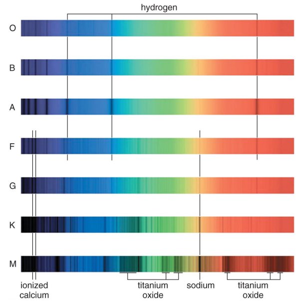
1. Hotter objects emit more light per unit area at all frequencies.
2. Hotter objects emit photons with a higher average energy.



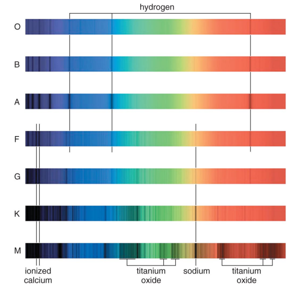
- Hottest stars: 50,000 K
- Coolest stars: 3000 K
- (Sun's surface is 5800 K.)



- Level of ionization also reveals a star's temperature.



- Absorption lines in star's spectrum tell us its ionization level.



- Lines in a star's spectrum correspond to a ***spectral type*** that reveals its temperature.

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

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

Thought Question

Which kind of star is hottest?

A. M star
B. F star
C. A star
D. K star

Thought Question

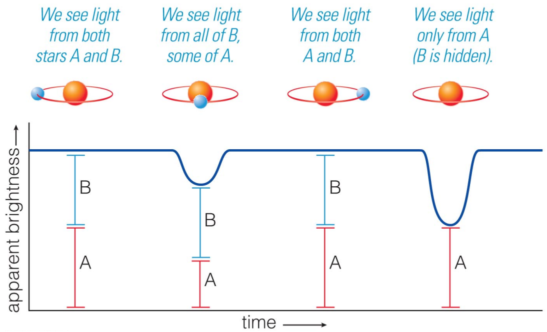
Which kind of star is hottest?

A. M star
B. F star
C. A star
D. K star

Pioneers of Stellar Classification

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

How do we measure stellar masses?



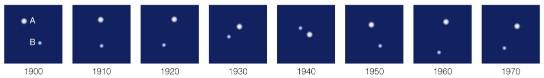
- The orbit of a binary star system depends on strength of gravity.

Types of Binary Star Systems

- Visual binary
- Spectroscopic binary
- Eclipsing binary

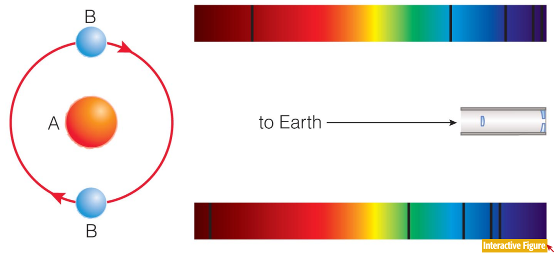
About half of all stars are in binary systems.

Visual Binary



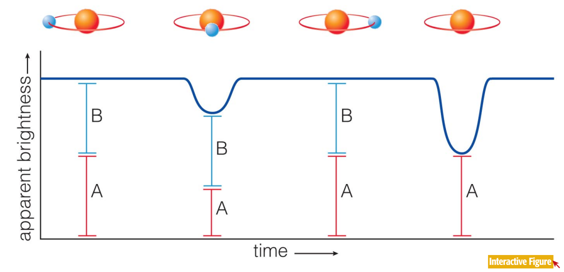
- We can directly observe the orbital motions of these stars.

Spectroscopic Binary



- We determine the orbit by measuring Doppler shifts.

Eclipsing Binary



- We can measure periodic eclipses.

We measure mass using gravity.

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

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

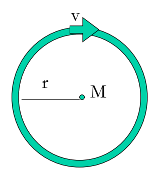
p = period

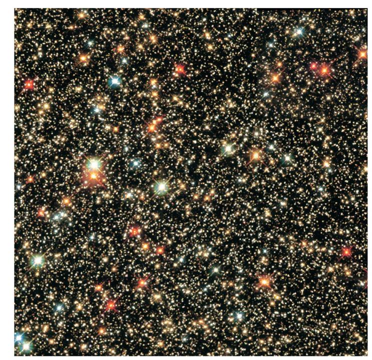
a = average separation

Need two out of three 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: $100M_{Sun}$
- Least massive stars: $0.08M_{Sun}$
- (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.

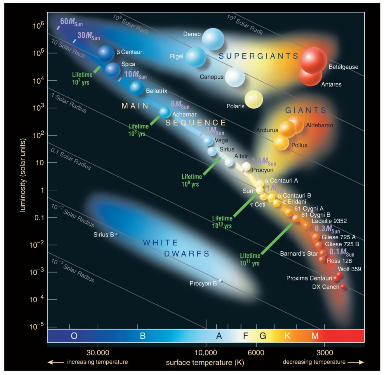
What have we learned?

- **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).

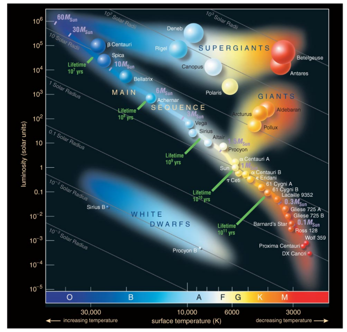
15.2 Patterns Among Stars

- 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?**

What is a Hertzsprung-Russell diagram?

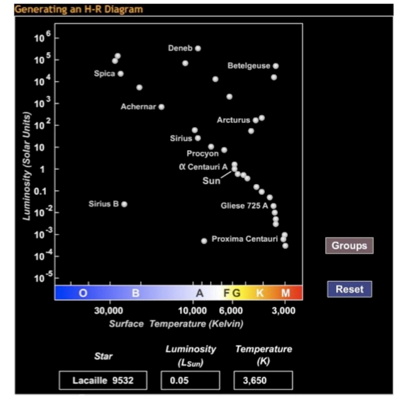


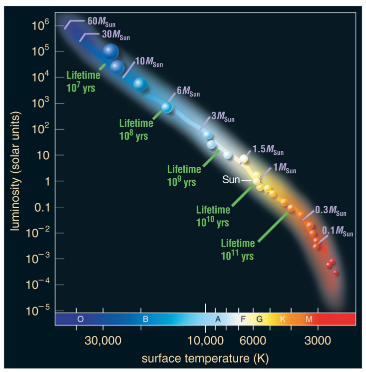
Luminosity



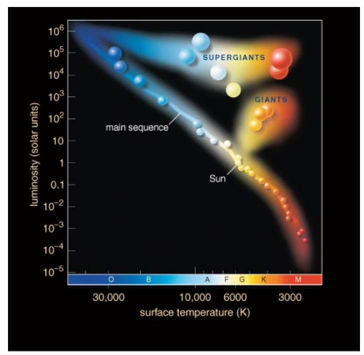
Temperature

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

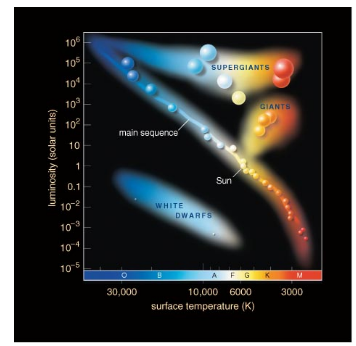




- Most stars fall somewhere on the ***main sequence*** of the H-R diagram.



- Stars with lower *T* and higher *L* than main-sequence stars must have larger radii. These stars are called ***giants*** and ***supergiants.***



- Stars with higher *T* and lower *L* than main-sequence stars must have smaller radii. These stars are called ***white dwarfs***.

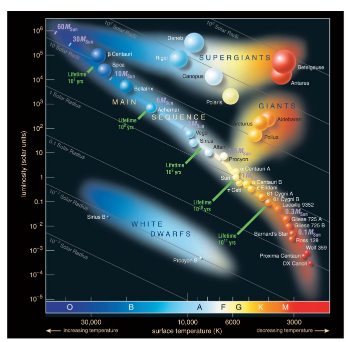
Stellar Luminosity Classes

- 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

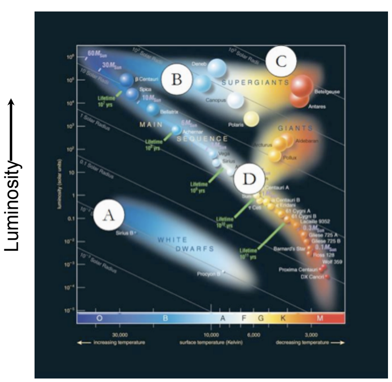


Temperature

- H-R diagram depicts:

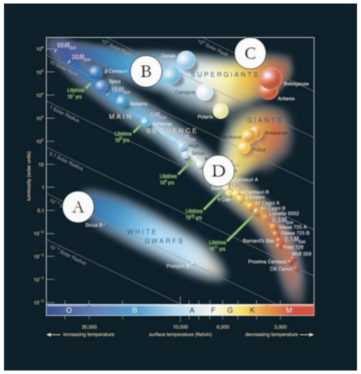
  Temperature
  Color Spectral type Luminosity
  Radius

Luminosity



Temperature

- Which star is the hottest?

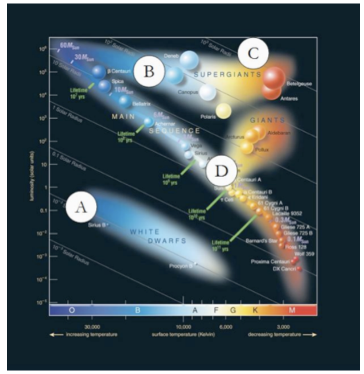


Luminosity

Temperature

- Which star is the hottest?

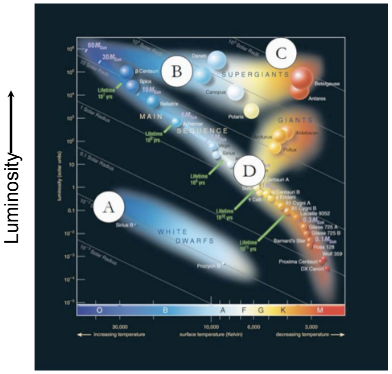
(A)



Luminosity

Temperature

- Which star is the most luminous?

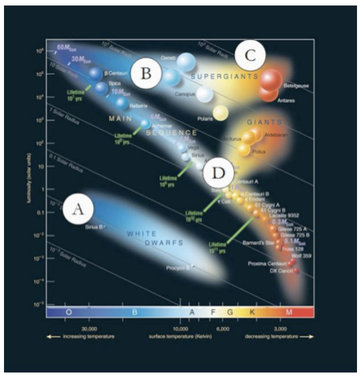


Luminosity

Temperature

- Which star is the most luminous?

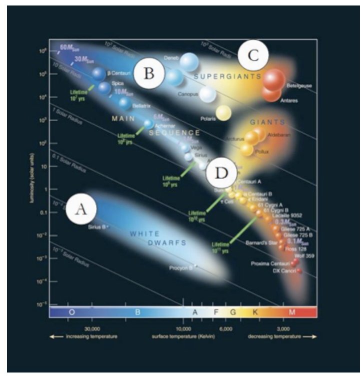
(C)



Luminosity

Temperature

- Which star is a main-sequence star?

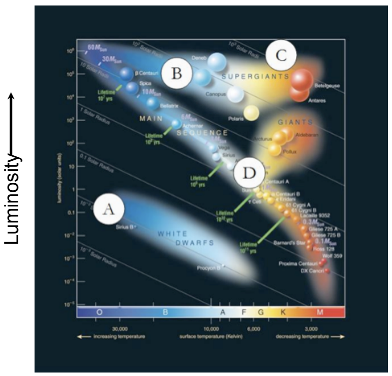


Luminosity

Temperature

- Which star is a main-sequence star?

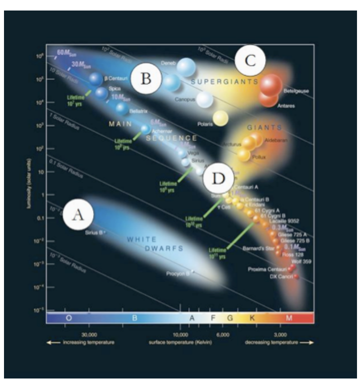
(D)



Luminosity

Temperature

- Which star has the largest radius?



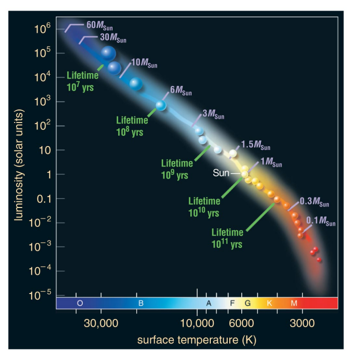
Luminosity

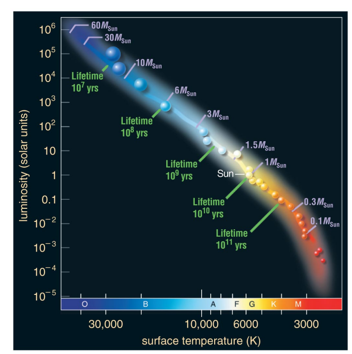
Temperature

- Which star has the largest radius?

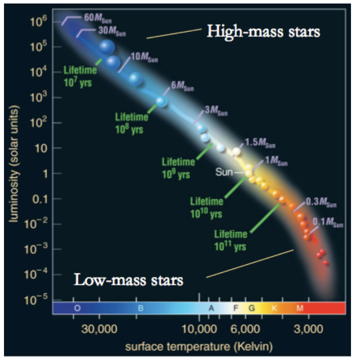
(C)

What is the significance of the main sequence?

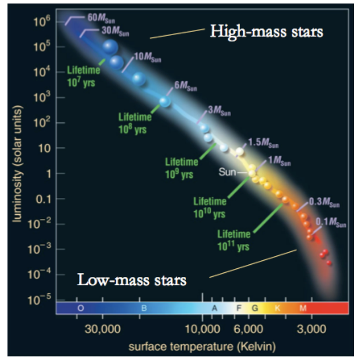




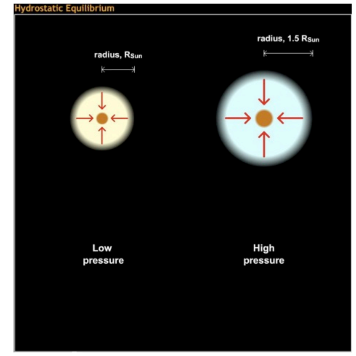
- ***Main-sequence stars*** are fusing hydrogen into helium in their cores like the Sun.
- Luminous main-sequence stars are hot (blue).
- Less luminous ones are cooler (yellow or red).



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



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



- 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

  $10^{-4}L_{Sun}$–$10^{6}L_{Sun}$

- ***Temperature:*** from color and spectral type

  3000 K–50,000 K

- ***Mass:*** from period (p) and average separation (a) of binary star orbit

  $0.08M_{Sun}$ – $100M_{Sun}$

Stellar Properties Review

- ***Luminosity:*** from brightness and distance

  ($0.08M_{Sun}$) $10^{-4}L_{Sun}$–$10^{6}L_{Sun}$ **($100M_{Sun}$)**

- ***Temperature:*** from color and spectral type

  ($0.08M_{Sun}$) 3000 K–50,000 K **($100M_{Sun}$)**

- ***Mass:*** from period (p) and average separation (a) of binary star orbit

  $0.08M_{Sun}$–$100M_{Sun}$

Mass and Lifetime

- ***Sun's life expectancy:*** 10 billion years

Mass and Lifetime

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Mass and Lifetime

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- ***Life expectancy of $10M_{Sun}$ star:***

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

  10 million years ~ 10 billion years × $10/10^4$

Mass and Lifetime

- ***Sun's life expectancy:*** <u>10 billion years</u> — **Until core hydrogen (10% of total) is used up**
- ***Life expectancy of $10M_{Sun}$ star:***

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

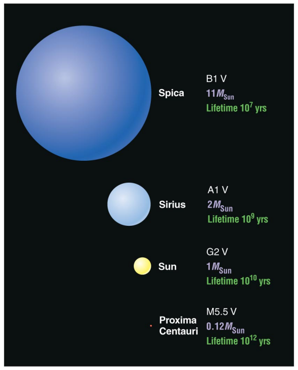
  <u>10 million years</u> ~ 10 billion years × $10/10^4$

- ***Life expectancy of $0.1M_{Sun}$ star:***

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

  <u>100 billion years</u> ~ 10 billion years × 0.1/0.01

Main-Sequence Star Summary

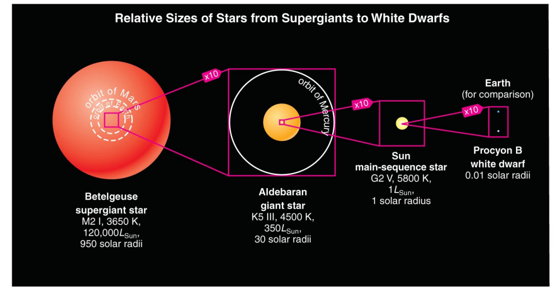


High-Mass Star:
- High luminosity
- Short-lived
- Larger radius
- Blue

Low-Mass Star:
- Low luminosity
- Long-lived
- Small radius
- Red

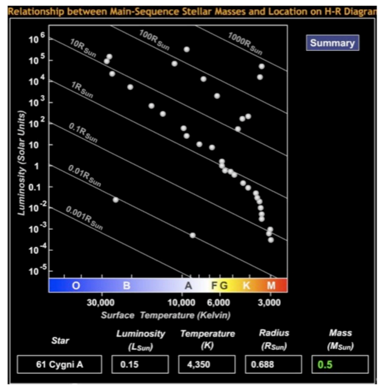
What are giants, supergiants, and white dwarfs?

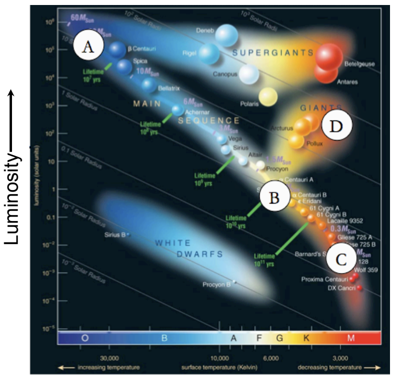
Sizes of Giants and Supergiants



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.**

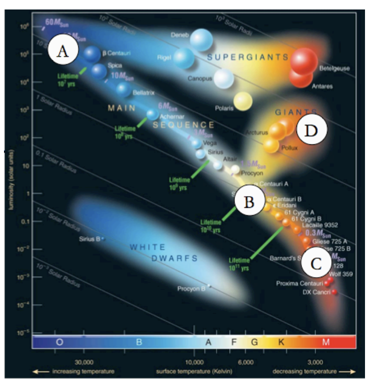




Luminosity

Temperature

- Which star is most like our Sun?

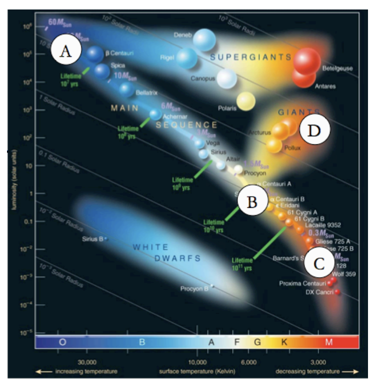


Luminosity

Temperature

- Which star is most like our Sun?

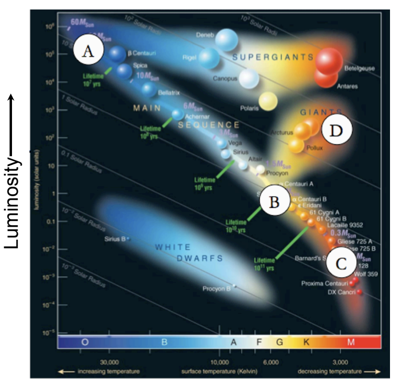
B



Luminosity

Temperature

- Which of these stars will have changed the least 10 billion years from now?

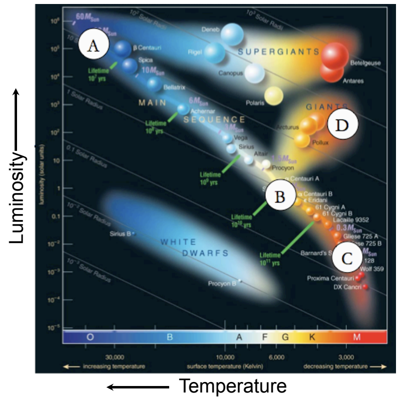


Luminosity

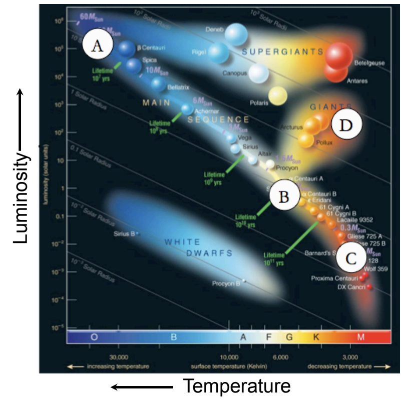
Temperature

- Which of these stars will have changed the least 10 billion years from now?

C



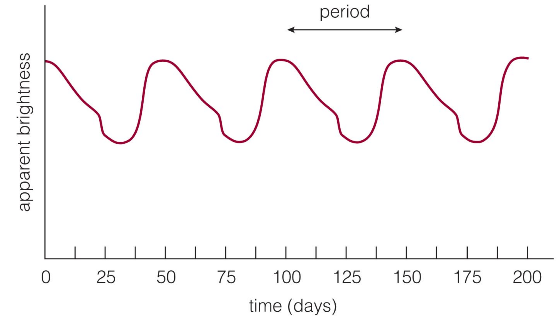
- Which of these stars can be no more than 10 million years old?



- Which of these stars can be no more than 10 million years old?

A

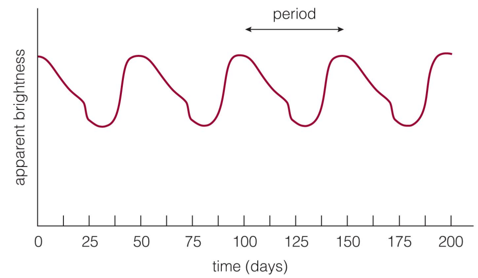
Why do the properties of some stars vary?



Variable Stars

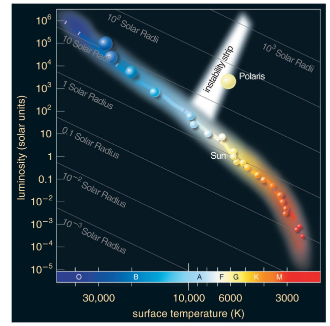
- Any star that varies significantly in brightness with time is called a *variable star*.
- Some stars vary in brightness because they cannot achieve proper balance between power welling up from the core and power radiated from the surface.
- Such a star alternately expands and contracts, varying in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

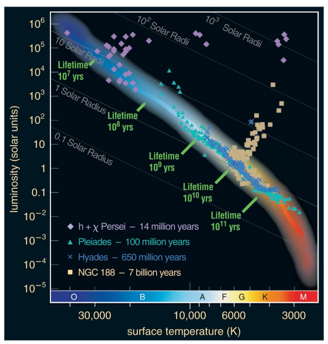
- Our goals for learning:
  - **What are the two types of star clusters?**
  - **How do we measure the age of a star cluster?**

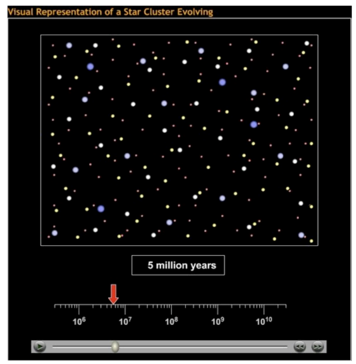
What are the two types of star clusters?

- ***Open cluster:*** A few thousand loosely packed stars

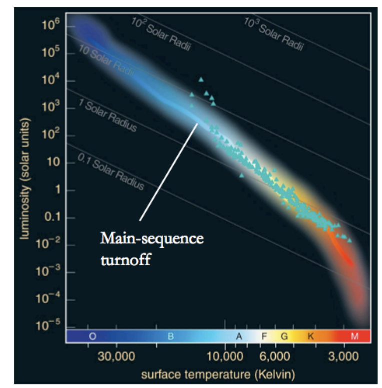
- ***Globular cluster:*** Up to a million or more stars in a dense ball bound together by gravity

How do we measure the age of a star cluster?

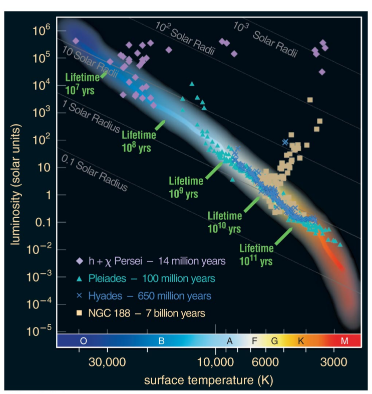




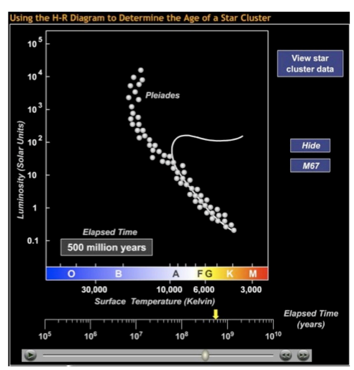
- Massive blue stars die first, followed by white, yellow, orange, and red stars.



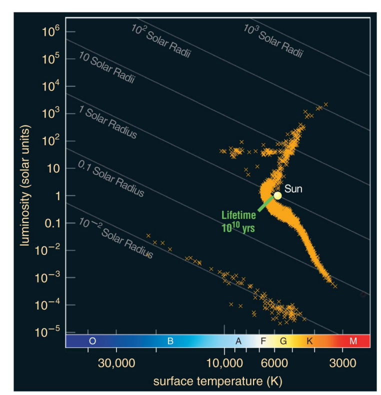
- The Pleiades cluster now has no stars with life expectancy less than around 100 million years.



- The 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.