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ASTRONOMY

Chapter 18 THE STARS: A CELESTIAL CENSUS

PowerPoint Image Slideshow

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18.1 A STELLAR CENSUS

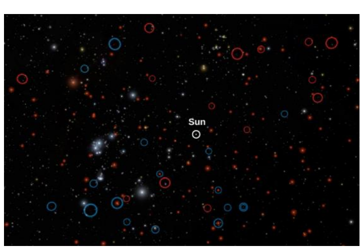
- **Variety of Stars.** Stars come in a variety of sizes, masses, temperatures, and luminosities. This image shows part of a cluster of stars in the Small Magellanic Cloud (catalog number NGC 290). Located about 200,000 light-years away, NGC 290 is about 65 light-years across. Because the stars in this cluster are all at about the same distance from us, the differences in apparent brightness correspond to differences in luminosity; differences in temperature account for the differences in color. The various colors and luminosities of these stars provide clues about their life stories.

Stars within 21 Light-Years of the Sun

Spectral Type	Number of Stars
A	2
F	1
G	7
K	17
M	94
White dwarfs	8
Brown dwarfs	33

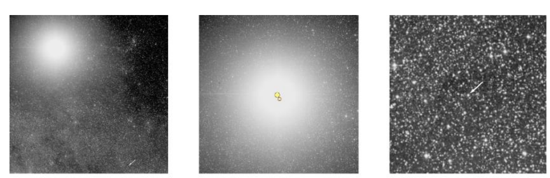
Table 18.1

Figure 18.2



- **Dwarf Simulation.** This computer simulation shows the stars in our neighborhood as they would be seen from a distance of 30 light-years away. The Sun is in the center. All the brown dwarfs are circled; those found earlier are circled in blue, the ones found recently with the WISE infrared telescope in space (whose scientists put this diagram together) are circled in red. The common M stars, which are red and faint, are made to look brighter than they really would be so that you can see them in the simulation. Note that luminous hot stars like our Sun are very rare. (credit: modification of work by NASA/ JPL-Caltech)

Figure 18.3



(a) (b) (c)

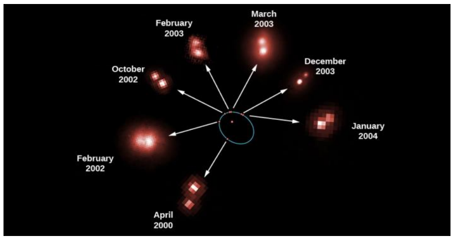
- **The Closest Stars.**

(a) This image, taken with a wide-angle telescope at the European Southern Observatory in Chile, shows the system of three stars that is our nearest neighbor.

(b) Two bright stars that are close to each other (Alpha Centauri A and B) blend their light together.

(c) Indicated with an arrow (since you'd hardly notice it otherwise) is the much fainter Proxima Centauri star, which is spectral type M. (credit: modification of work by ESO)

18.2+18.3 MEASURING STELLAR MASSES & DIAMETERS



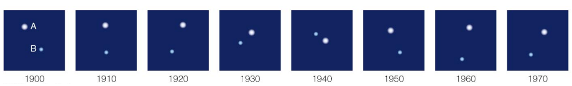
- **Revolution of a Binary Star.** This figure shows revolution of two stars, one a brown dwarf and one an ultra-cool L dwarf. Each red dot on the orbit, which is shown by the blue ellipse, corresponds to the position of one of the dwarfs relative to the other. The reason that the pair of stars looks different on the different dates is that some images were taken with the Hubble Space Telescope and others were taken from the ground.. From these observations, an international team of astronomers directly measured the mass. Barely the size of the planet Jupiter, the dwarf star weighs in at just 8.5% of the mass of our Sun.

Types of Binary Star Systems

- Visual binary
- Eclipsing binary
- Spectroscopic binary

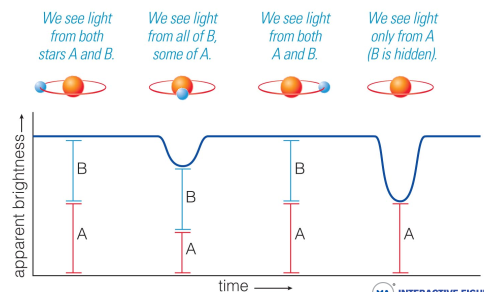
About half of all stars are in binary systems.

Visual Binary



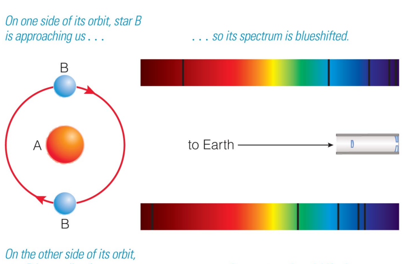
We can directly observe the orbital motions of these stars.

Eclipsing Binary



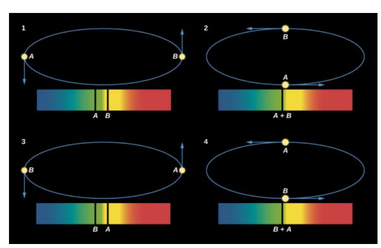
We can measure periodic eclipses.

Spectroscopic Binary



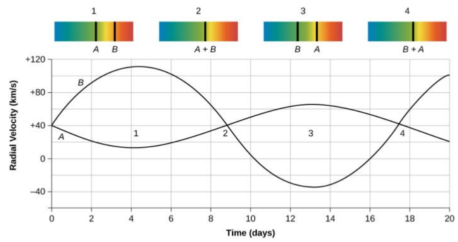
We determine the orbit by measuring Doppler shifts.

Figure 18.6



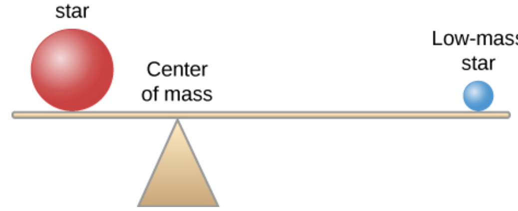
- **Motions of Two Stars Orbiting Each Other and What the Spectrum Shows.** We see changes in velocity because when one star is moving toward Earth, the other is moving away; half a cycle later, the situation is reversed. Doppler shifts cause the spectral lines to move back and forth. In diagrams 1 and 3, lines from both stars can be seen well separated from each other. When the two stars are moving perpendicular to our line of sight (that is, they are not moving either toward or away from us), the two lines are exactly superimposed, and so in diagrams 2 and 4, we see only a single spectral line.

Figure 18.7



- **Radial Velocities in a Spectroscopic Binary System.** These curves plot the radial velocities of two stars in a spectroscopic binary system, showing how the stars alternately approach and recede from Earth. Note that positive velocity means the star is moving away from us relative to the center of mass of the system, which in this case is 40 kilometers per second. Negative velocity means the star is moving toward us relative to the center of mass. The positions on the curve corresponding to the illustrations in Figure 18.6 are marked with the diagram number (1–4).

Figure 18.5



- **Binary Star System.** In a binary star system, both stars orbit their center of mass. The image shows the relative positions of two, different-mass stars from their center of mass, similar to how two masses would have to be located on a seesaw in order to keep it level. The star with the higher mass will be found closer to the center of mass, while the star with the lower mass will be farther from it.

Isaac Newton

We measure mass using gravity.

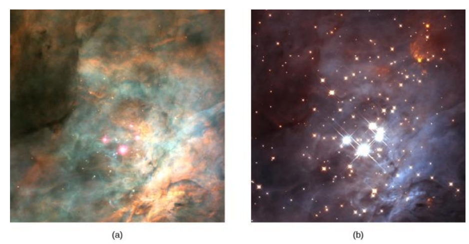
Direct mass measurements are possible only for stars in binary star systems.

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

p = period

a = average separation

Figure 18.8

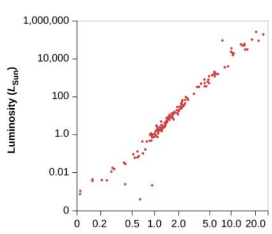


- **Brown Dwarfs in Orion.** These images, taken with the Hubble Space Telescope, show the region surrounding the Trapezium star cluster inside the star-forming region called the Orion Nebula.

(a) No brown dwarfs are seen in the visible light image, both because they put out very little light in the visible and because they are hidden within the clouds of dust in this region.

(b) This image was taken in infrared light, which can make its way to us through the dust. The faintest objects in this image are brown dwarfs with masses between 13 and 80 times the mass of Jupiter.

Figure 18.9



- **Mass-Luminosity Relation.** The plotted points show the masses and luminosities of stars. The three points lying below the sequence of points are all white dwarf stars.

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, $v = 2\pi r / p$

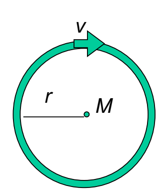


Figure 18.10

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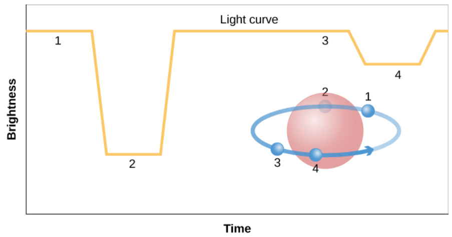

Light Curve of an Eclipsing Binary. The light curve of an eclipsing binary star system shows how the combined light from both stars changes due to eclipses over the time span of an orbit. This light curve shows the behavior of a hypothetical eclipsing binary star with total eclipses (one star passes directly in front of and behind the other).

Stellar Diameters

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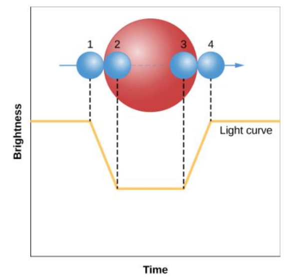


Light Curve of an Edge-On Eclipsing Binary. Here we see the light curve of a hypothetical eclipsing binary star whose orbit we view exactly edge-on, in which the two stars fully eclipse each other. From the time intervals between contacts, it is possible to estimate the diameters of the two stars.

Most luminous stars:

$10^6 L_{Sun}$

Least luminous stars:

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

(L_{Sun} is luminosity of the Sun)

Most massive stars:

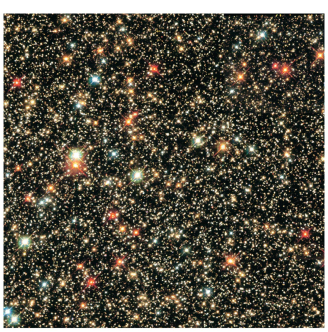
$100 M_{Sun}$

(some very rare stars may have $> 100\ M_{Sun}$)

Least massive stars:

$0.08 M_{Sun}$

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



Hottest stars:

50,000 K

Coolest stars:

3000 K

(Sun's surface is 5800 K)

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

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

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

$0.08 M_{Sun} - 100 M_{Sun}$

18.4 THE H–R DIAGRAM

(a) (b)

- **Hertzsprung (1873–1967) and Russell (1877–1957).** (a) Ejnar Hertzsprung and (b) Henry Norris Russell independently discovered the relationship between the luminosity and surface temperature of stars that is summarized in what is now called the H–R diagram.

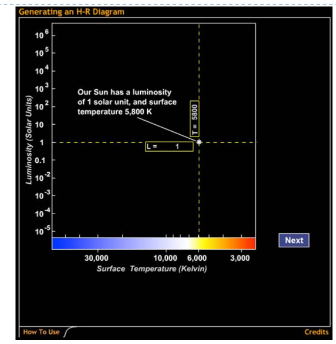
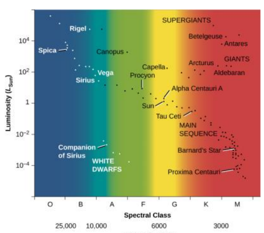
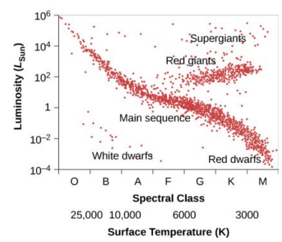


Figure 18.14

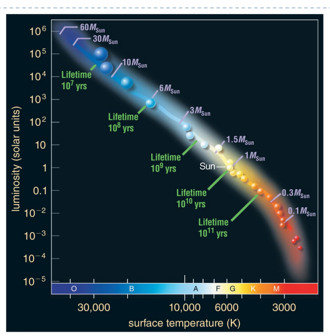


- **H–R Diagram for a Selected Sample of Stars.** In such diagrams, luminosity is plotted along the vertical axis. Along the horizontal axis, we can plot either temperature or spectral type (also sometimes called spectral class). Several of the brightest stars are identified by name. Most stars fall on the main sequence.

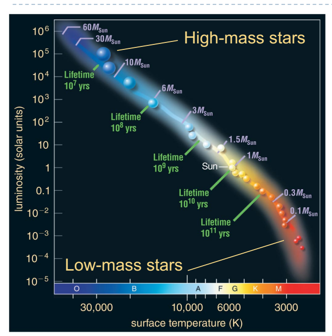
Figure 18.15



- **Schematic H–R Diagram for Many Stars.** Ninety percent of all stars on such a diagram fall along a narrow band called the main sequence. A minority of stars are found in the upper right; they are both cool (and hence red) and bright, and must be giants. Some stars fall in the lower left of the diagram; they are both hot and dim, and must be white dwarfs.

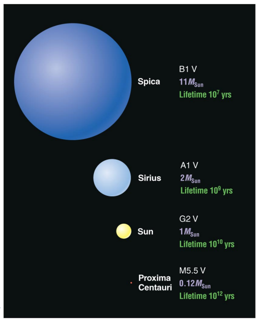


Most stars fall somewhere on the ***main sequence*** of the H-R diagram.



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

Main-Sequence Star Summary

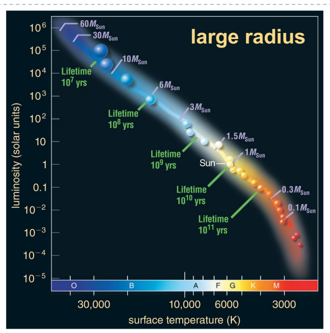


High-mass:
High luminosity
Short-lived
Large radius
Blue

Low-mass:
Low luminosity
Long-lived
Small radius
Red

Off the Main Sequence

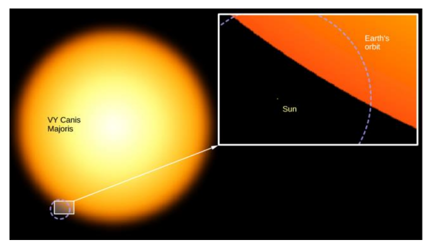
- Stellar properties depend on both mass and age: those that have finished fusing H to He in their cores are no longer on the main sequence.
- All stars become larger and redder after exhausting their core hydrogen: **giants** and **supergiants.**
- Most stars end up small and white after fusion has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



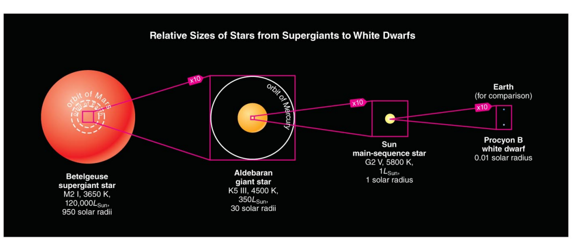
Stars with lower T and higher L than main-sequence stars must have larger radii:

giants and ***supergiants***

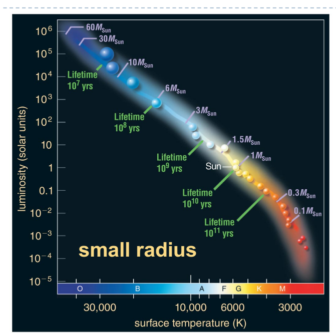
Figure 18.16



- **The Sun and a Supergiant.** Here you see how small the Sun looks in comparison to one of the largest known stars: VY Canis Majoris, a supergiant.



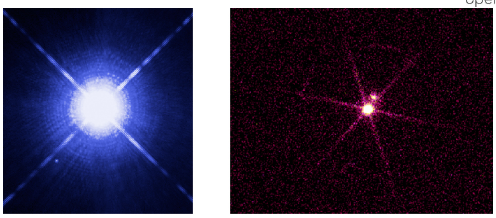
Giants and supergiants are far larger than main-sequence stars and white dwarfs.



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

white dwarfs

Figure 18.17



(a) (b)

Two Views of Sirius and Its White Dwarf Companion.

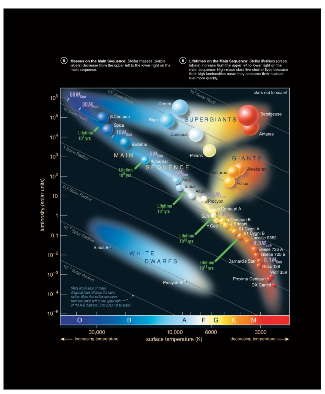
(a) The (visible light) image, taken with the Hubble Space Telescope, shows bright Sirius A, and, below it and off to its left, faint Sirius B.

(b) This image of the Sirius star system was taken with the Chandra X-Ray Telescope. Now, the bright object is the white dwarf companion, Sirius B. Sirius A is the faint object above it; what we are seeing from Sirius is probably not actually X-ray radiation but rather ultraviolet light that has leaked into the detector.

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



H-R diagram depicts:

Temperature
Color
Spectral type
Luminosity
Radius
Life expectancy

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

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

Life expectancy of a $10M_{Sun}$ star:

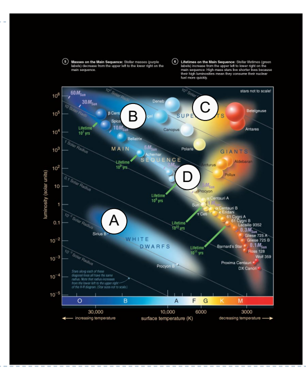
10 times as much fuel, uses it 10^4 times as fast

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

Life expectancy of a $0.1M_{Sun}$ star:

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

100 billion years ~ 10 billion years × 0.1/0.01



Which star is a main-sequence star?

Which star is the hottest?

Which star is the most luminous?

Which star has the largest radius?

Links

- brown white dwarfs 1 min

Reading

- 18.1
- 18.2
- 18.3
- 18.4