Neil F. Comins

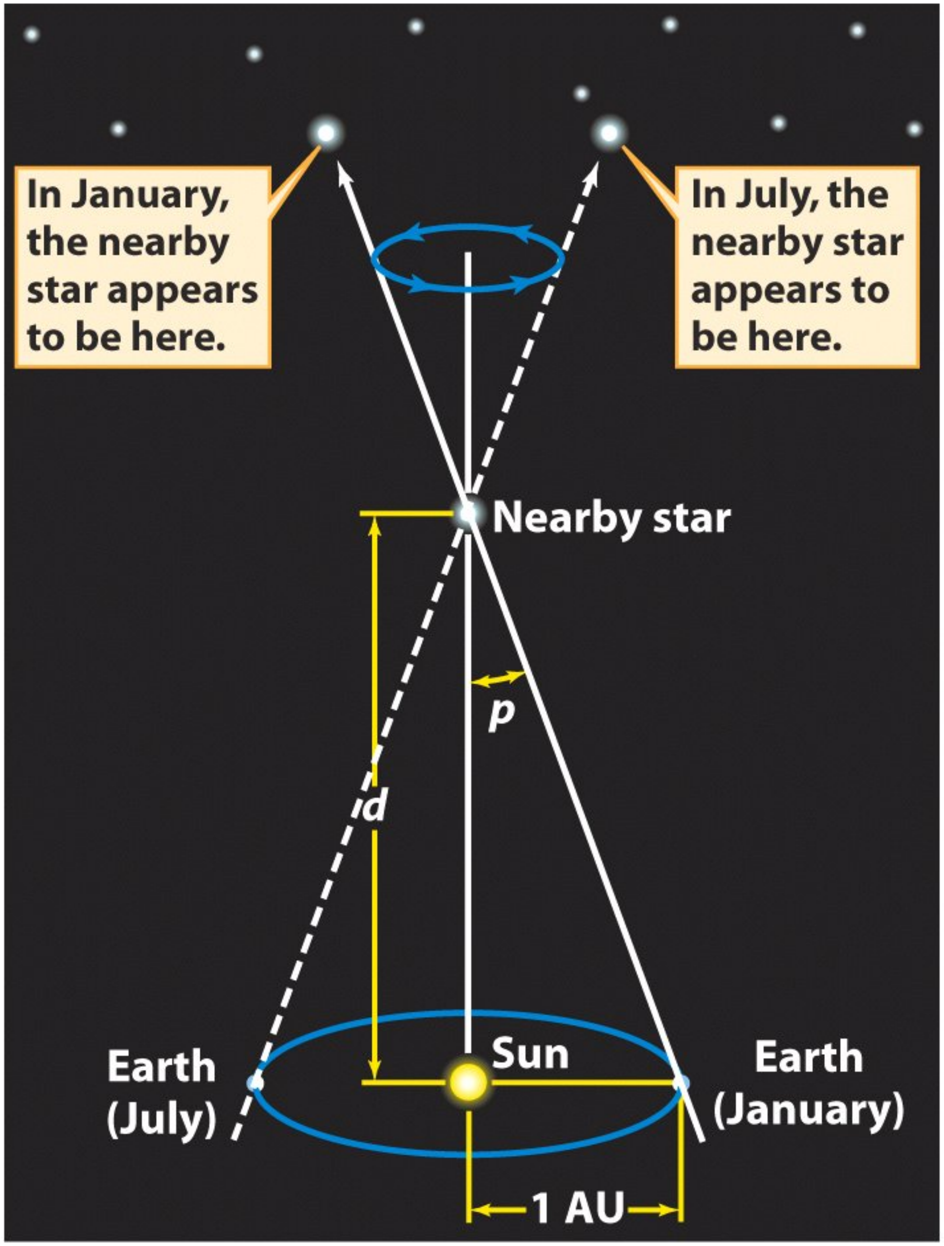
Discovering the Essential Universe

Sixth Edition

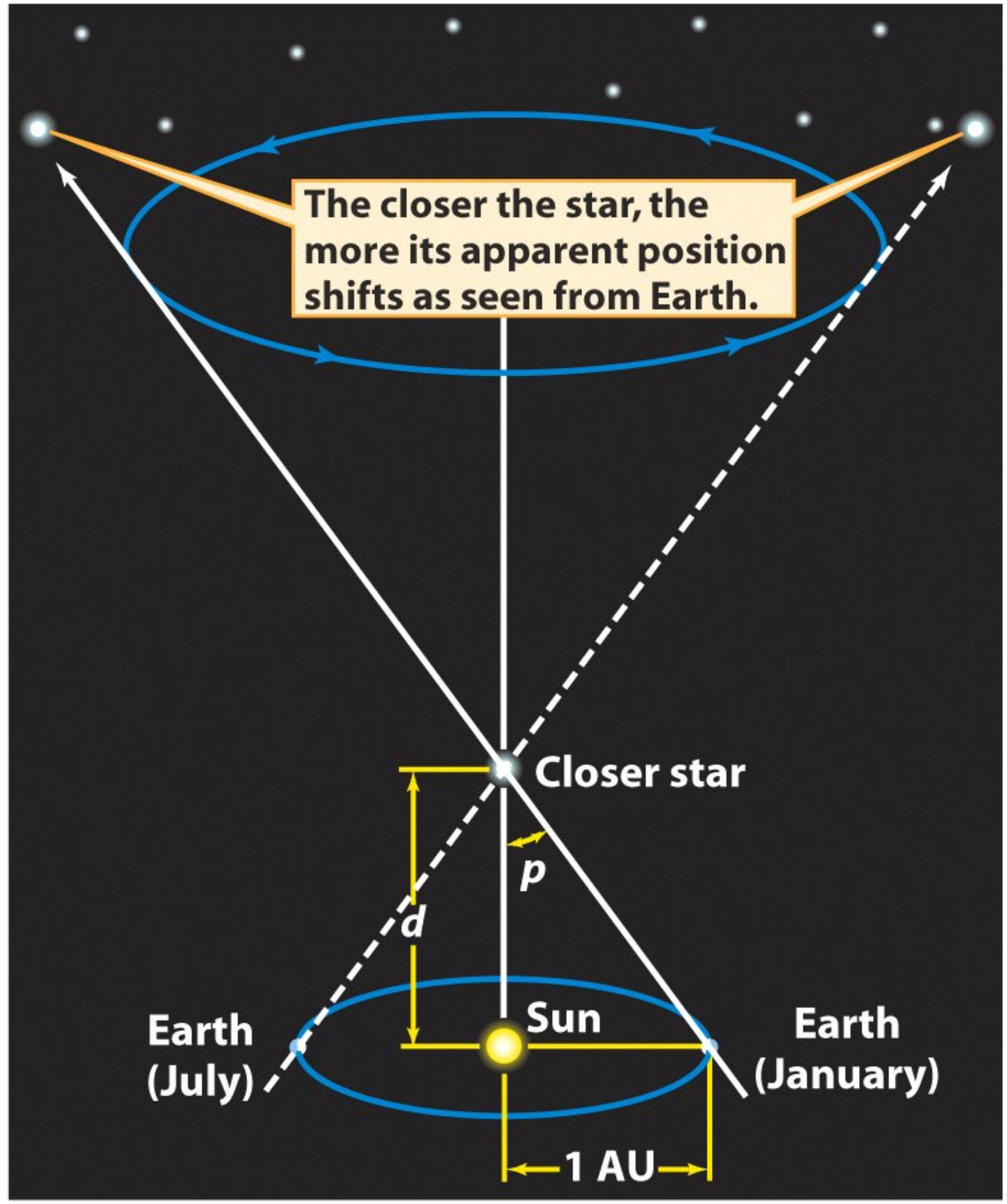
CHAPTER 10

Characterizing Stars

Distance, d



Parallax of a nearby star



Parallax of an even closer star

Careful measurements of the parallaxes of stars reveal their distances

Relation between a star's distance and its parallax

$$d = \frac{1}{p}$$

d = distance to a star, in parsecs

p = parallax angle of that star, in arcseconds

- Distances to the nearer stars can be determined by parallax, the apparent shift of a star against the background stars observed as the Earth moves along its orbit
- Parallax measurements made from orbit, above the blurring effects of the atmosphere, are much more accurate than those made with Earth-based telescopes
- Stellar parallaxes can only be measured for stars within a few hundred parsecs

If a star's distance is known, its luminosity can be determined from its brightness

Inverse-square law relating apparent brightness and luminosity

$$b = \frac{L}{4\pi d^2}$$

b = apparent brightness of a star's light, in W/m^2

L = star's luminosity, in W

d = distance to star, in meters

- A star's luminosity (total power of light output), apparent brightness, and distance from the Earth are related by the inverse-square law
- If any two of these quantities are known, the third can be calculated

Determining a star's luminosity from its apparent brightness

$$\frac{L}{L_{\odot}} = \left(\frac{d}{d_{\odot}}\right)^2 \frac{b}{b_{\odot}}$$

$L/L_{\odot}$ = ratio of the star's luminosity to the Sun's luminosity

$d/d_{\odot}$ = ratio of the star's distance to the Earth-Sun distance

$b/b_{\odot}$ = ratio of the star's apparent brightness to the Sun's apparent brightness

Astronomers often use the magnitude scale to denote brightness

Introduced by Hipparchus 129 BC

The **apparent magnitude,** m, is an alternative quantity that measures a star's apparent brightness

A 1st mag star is 100 times brighter than a 6th mag star (definition).

Then a 1st mag star is $\sqrt[5]{100}$ = 2.512 times brighter than a 2nd mag star and $(2.512)^2$ times brighter than a 3rd mag star and …

$$m_2 - m_1 = 2.5 \log (b_1/b_2)$$

The **absolute magnitude,** M, of a star is the apparent magnitude it would have if viewed from a distance of 10 pc

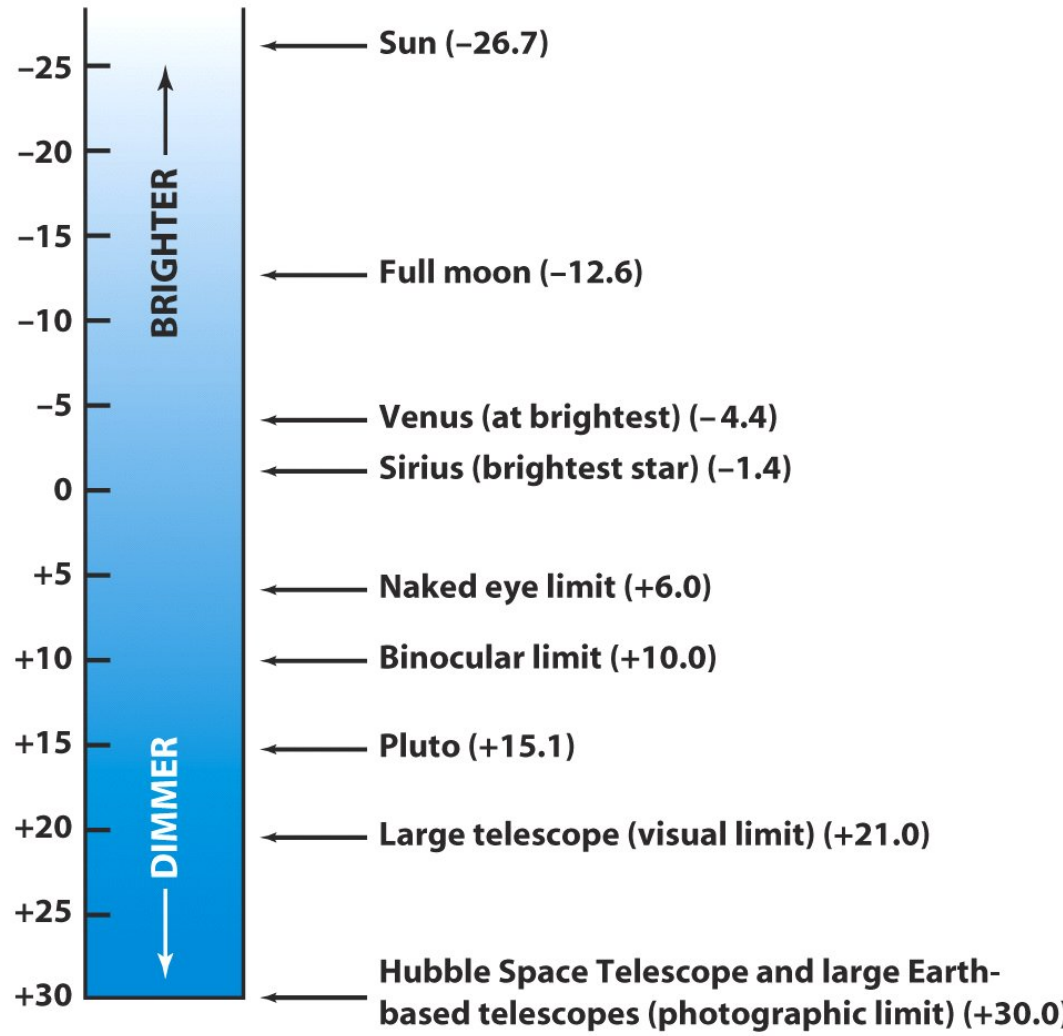
$$m - M = 5 \log (d) - 5$$

M of Sun?

$M = -5 \log (d) + 5 + m$

$M = -5 \log (1/206265) +5 + (-26.7)$

$M = 4.8$



Some apparent magnitudes

Distance Modulus

- Consider a star with apparent magnitude, m, and absolute magnitude, M. Then
- $m - M = 5 \log(d) - 5$
- Note that d is in pc
- Further, if d = 10 pc then

$$m - M = 5 \log(10) - 5$$

$$m - M = 5 - 5$$

$$= 0$$

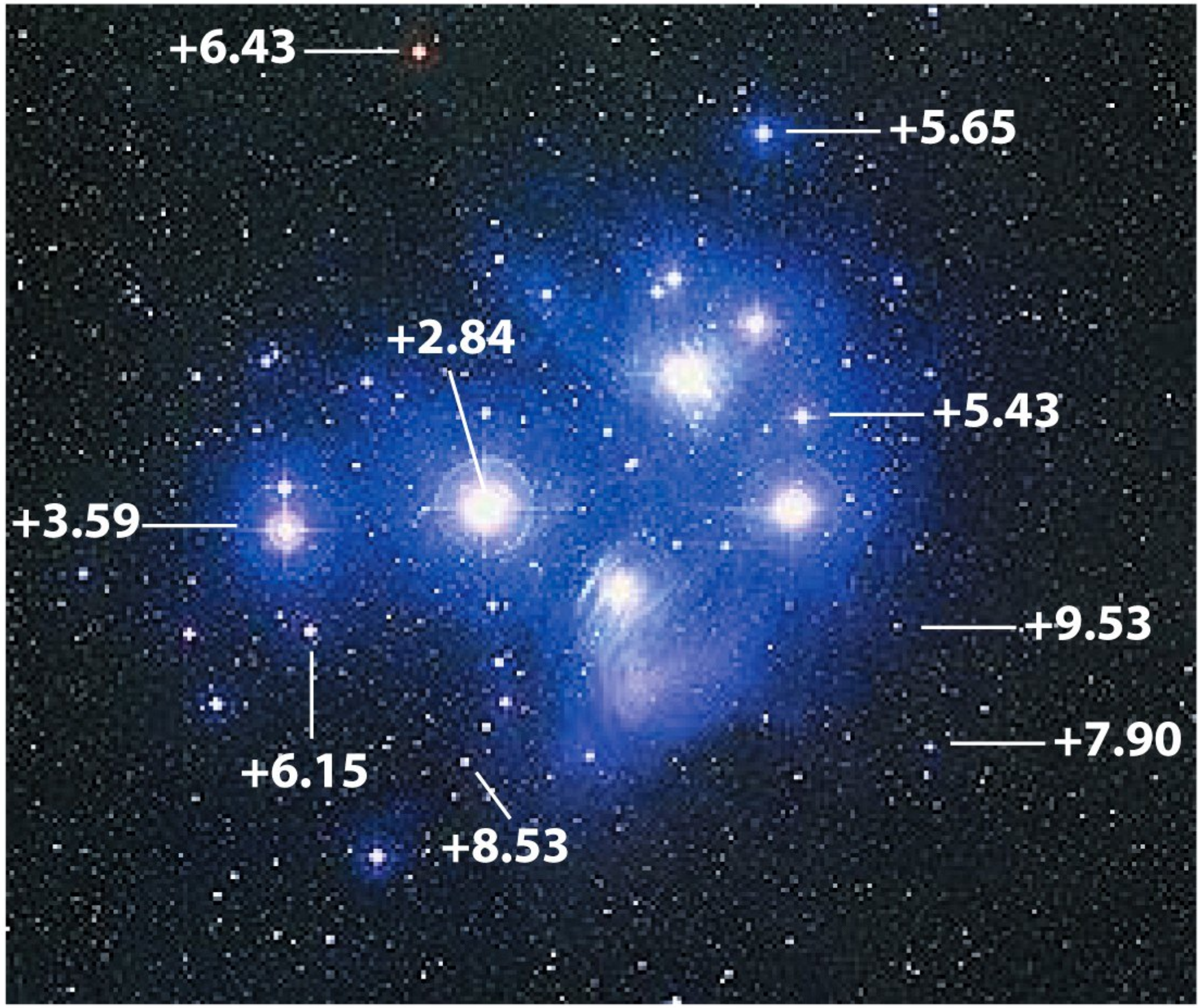
- m – M is called the distance modulus

What would be the apparent magnitude of the Sun at d = 120 pc?

$m - M = 5\log(d) - 5$

$m = 5\log(120) - 5 + 4.8$

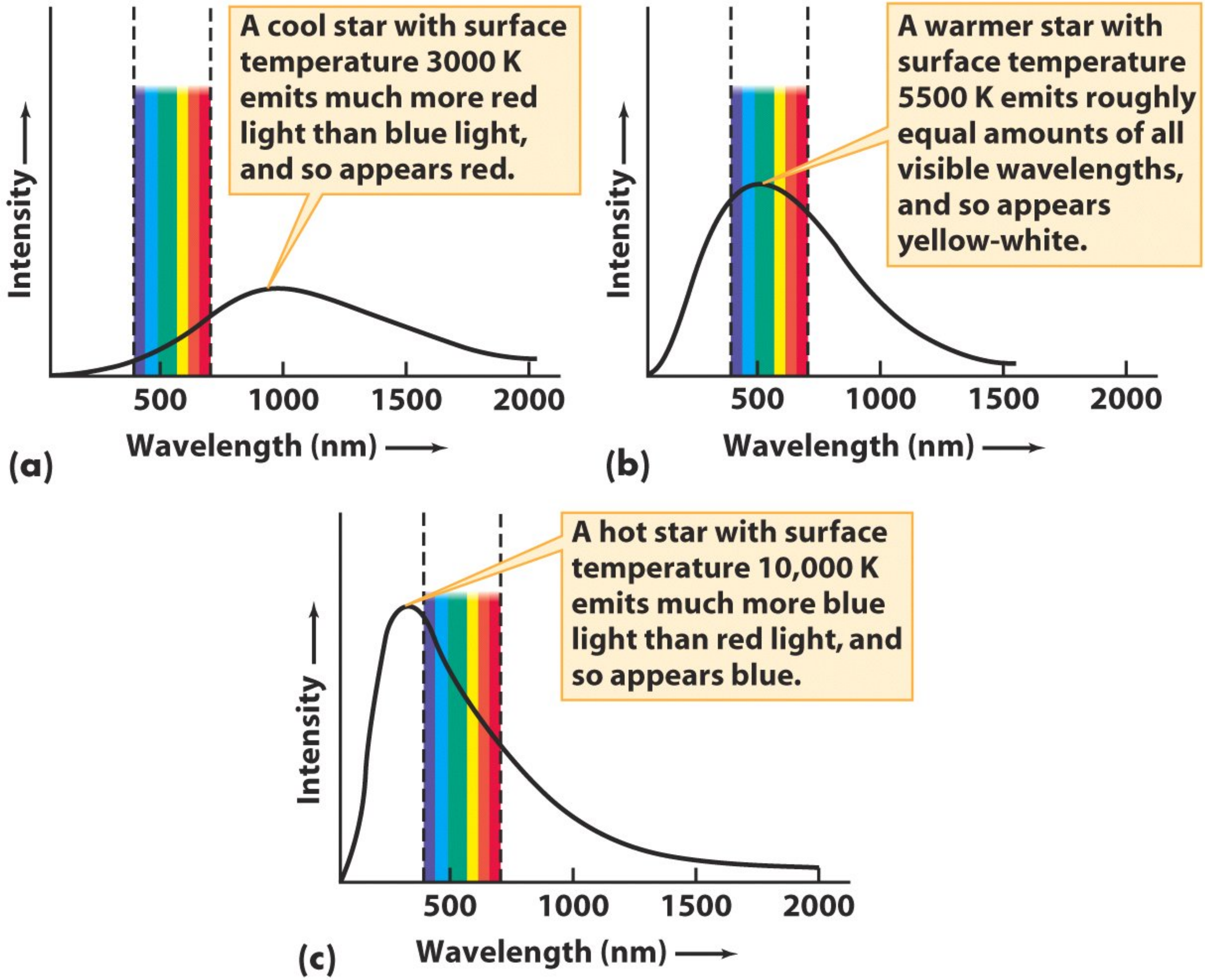
$m = 10.2$



Apparent magnitudes of stars in the Pleiades

d = 120 pc

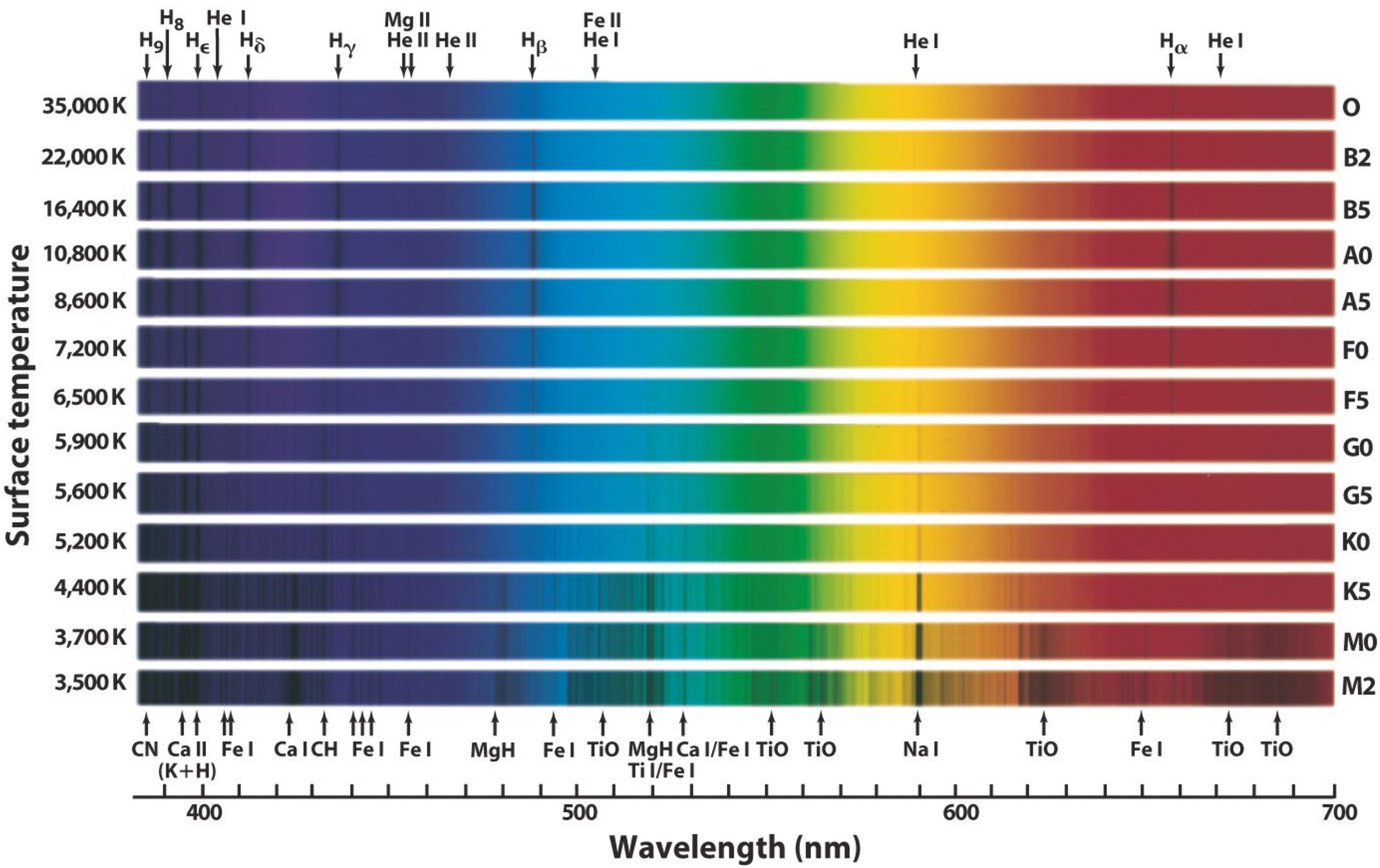
A star's color depends on its surface temperature



The spectra of stars reveal their chemical compositions as well as surface temperatures

- Stars are classified into spectral types (subdivisions of the spectral classes O, B, A, F, G, K, and M), based on the major patterns of spectral lines in their spectra

Spectra of stars with different T



Relationship between a star's luminosity, radius, and surface temperature

$$L = 4\pi R^2 \sigma T^4$$

L = star's luminosity, in watts

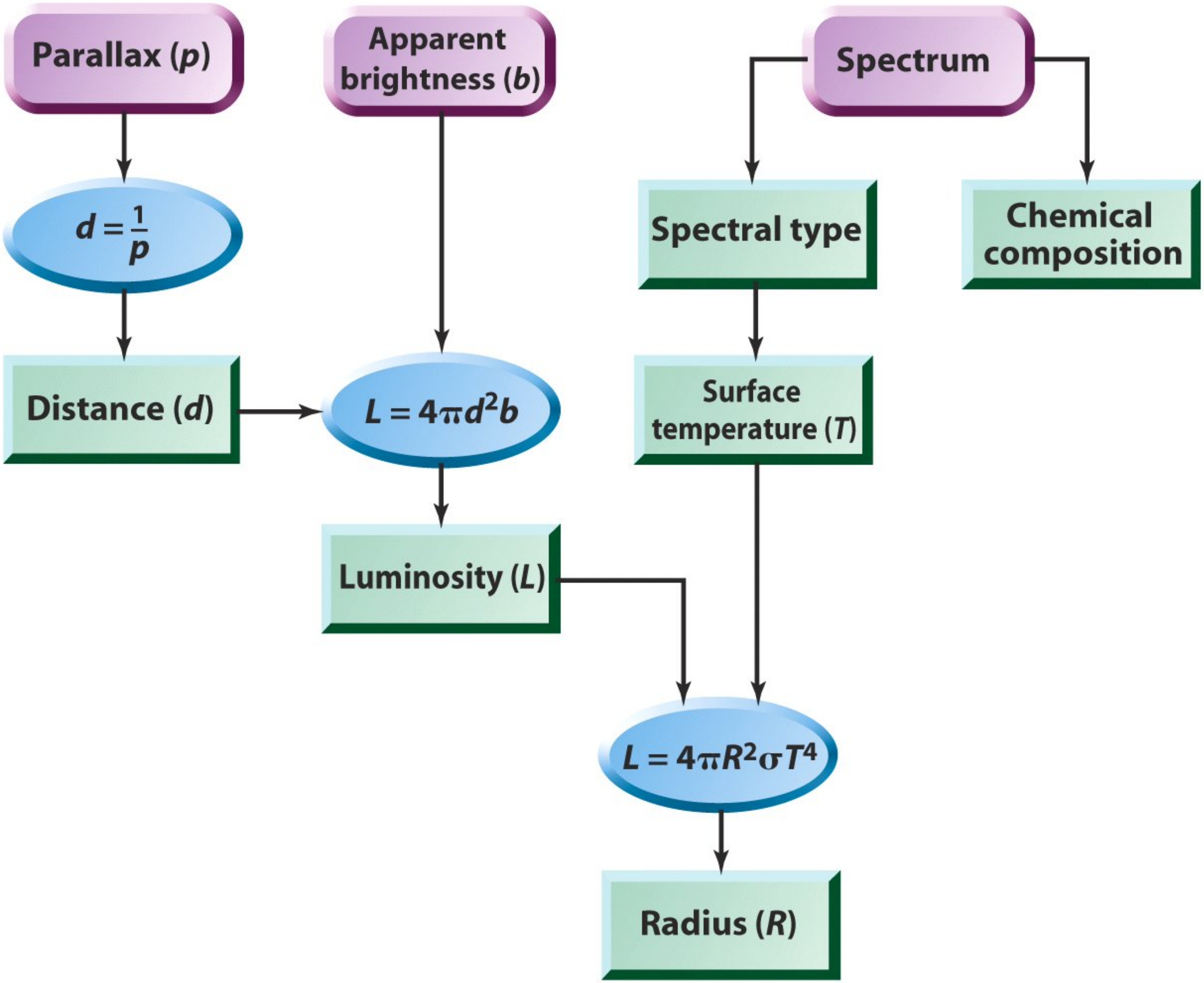
R = star's radius, in meters

σ = Stefan-Boltzmann constant = 5.67×10^{-8} W m^{-2} K^{-4}

T = star's surface temperature, in kelvins

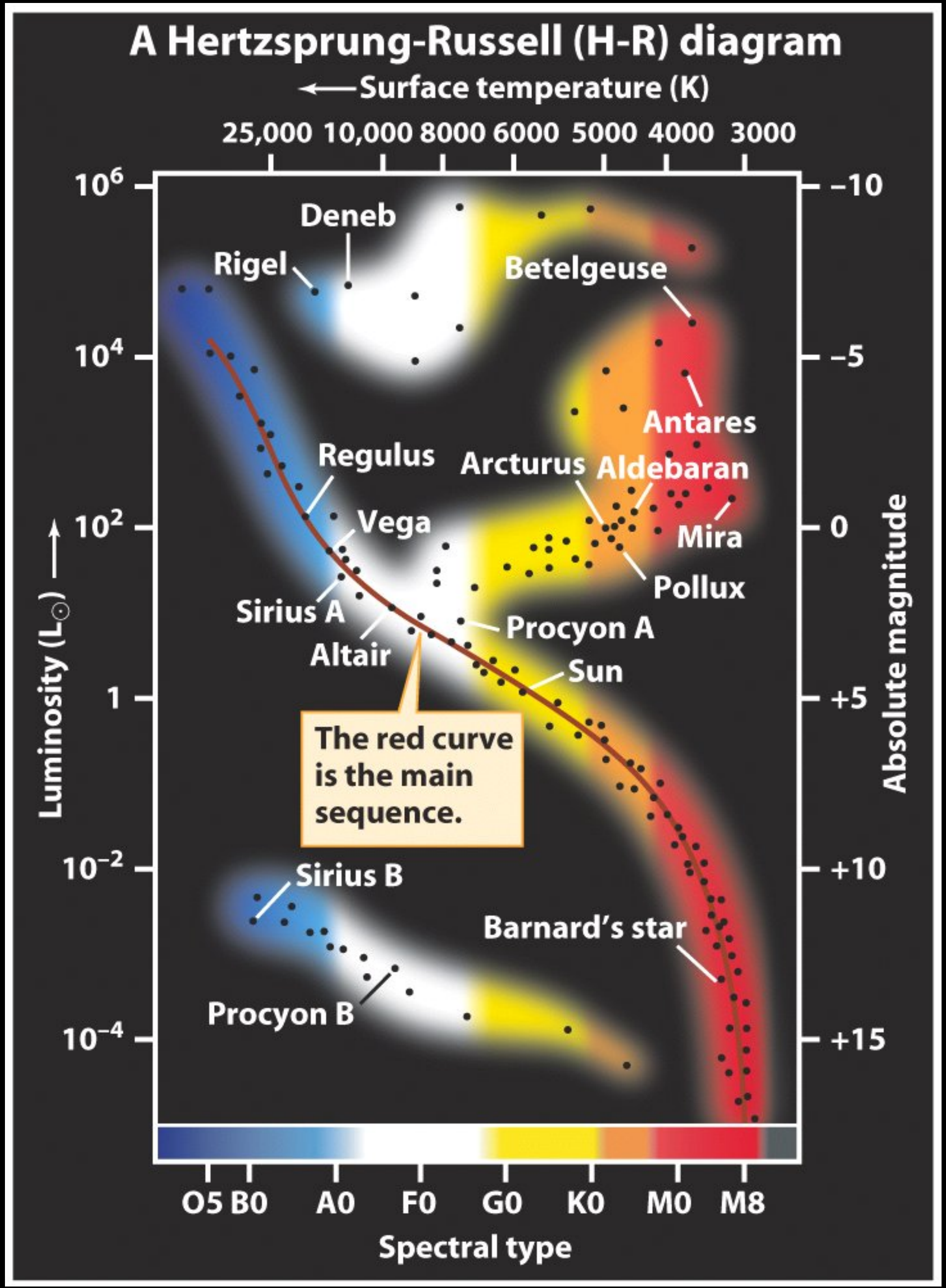
Stars come in a wide variety of sizes

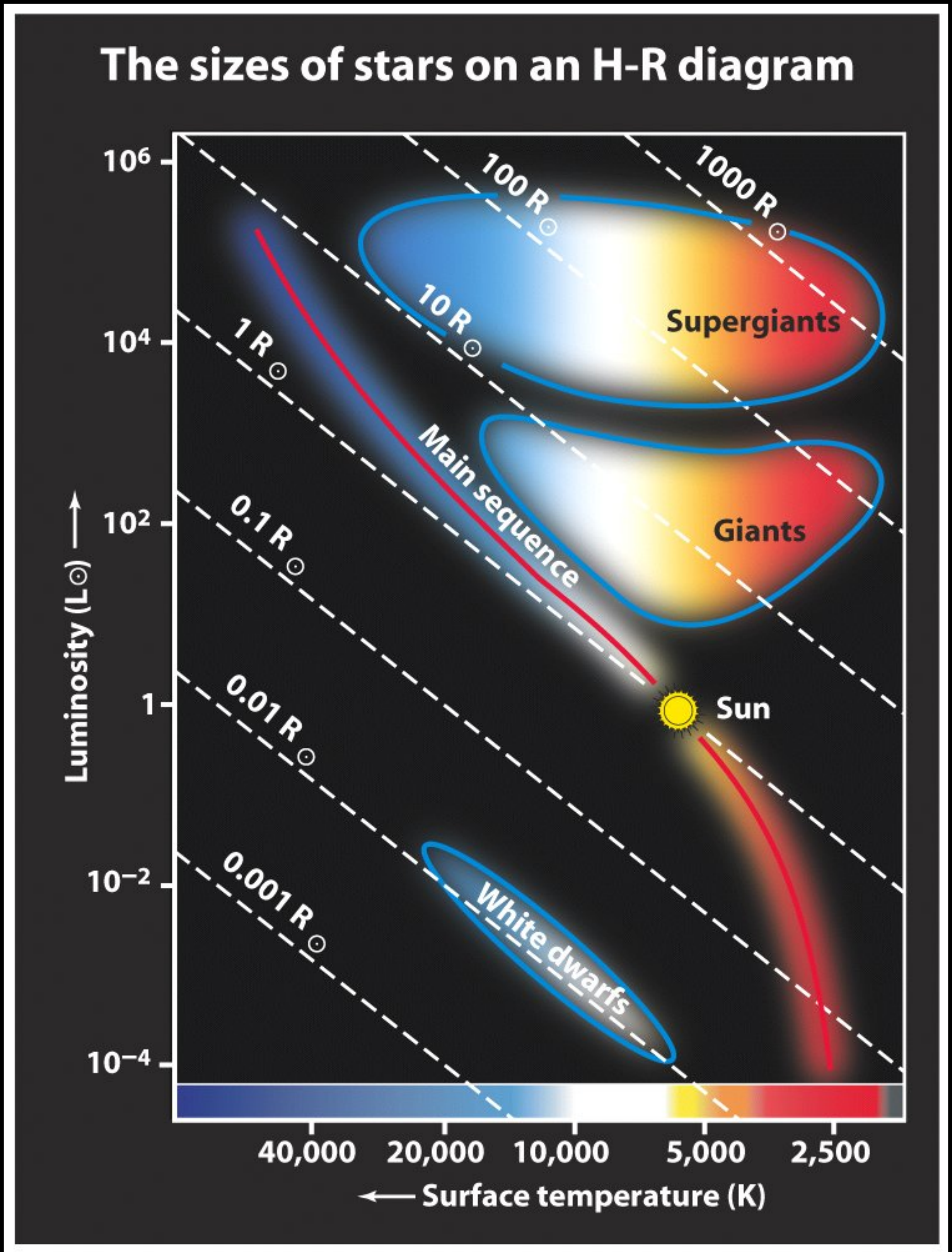
Finding Key Properties of Nearby Stars



Hertzsprung-Russell (H-R) diagrams reveal the different kinds of stars

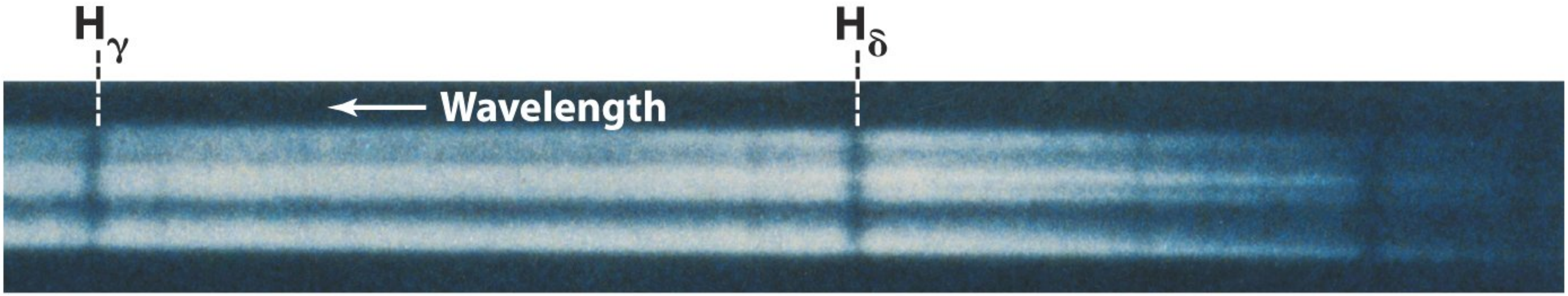
- The H-R diagram is a graph plotting the absolute magnitudes of stars against their spectral types—or, equivalently, their luminosities against surface temperatures
- The positions on the H-R diagram of most stars are along the main sequence, a band that extends from high luminosity and high surface temperature to low luminosity and low surface temperature



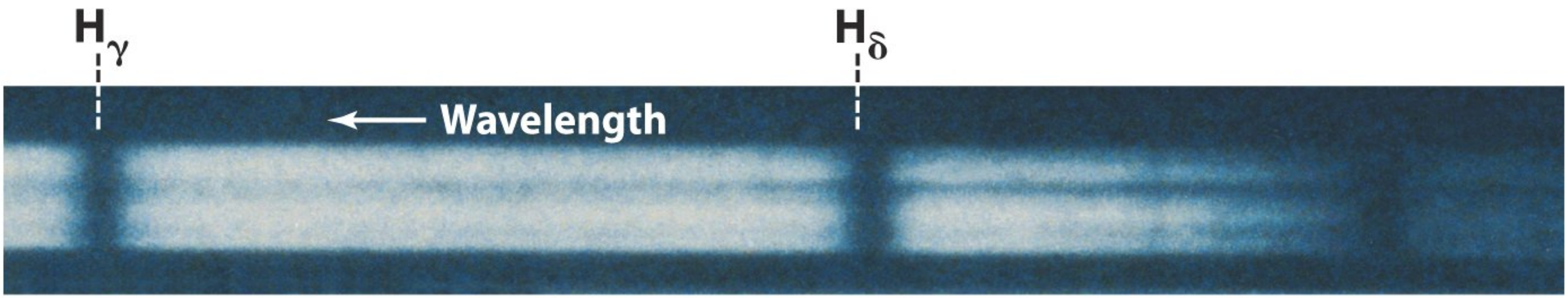


$$L = 4\pi R^2 \sigma T^4$$
$$R = [L/(4\pi\sigma T^4)]^{1/2}$$

On the H-R diagram, giant and supergiant stars lie above the main sequence, while white dwarfs are below the main sequence



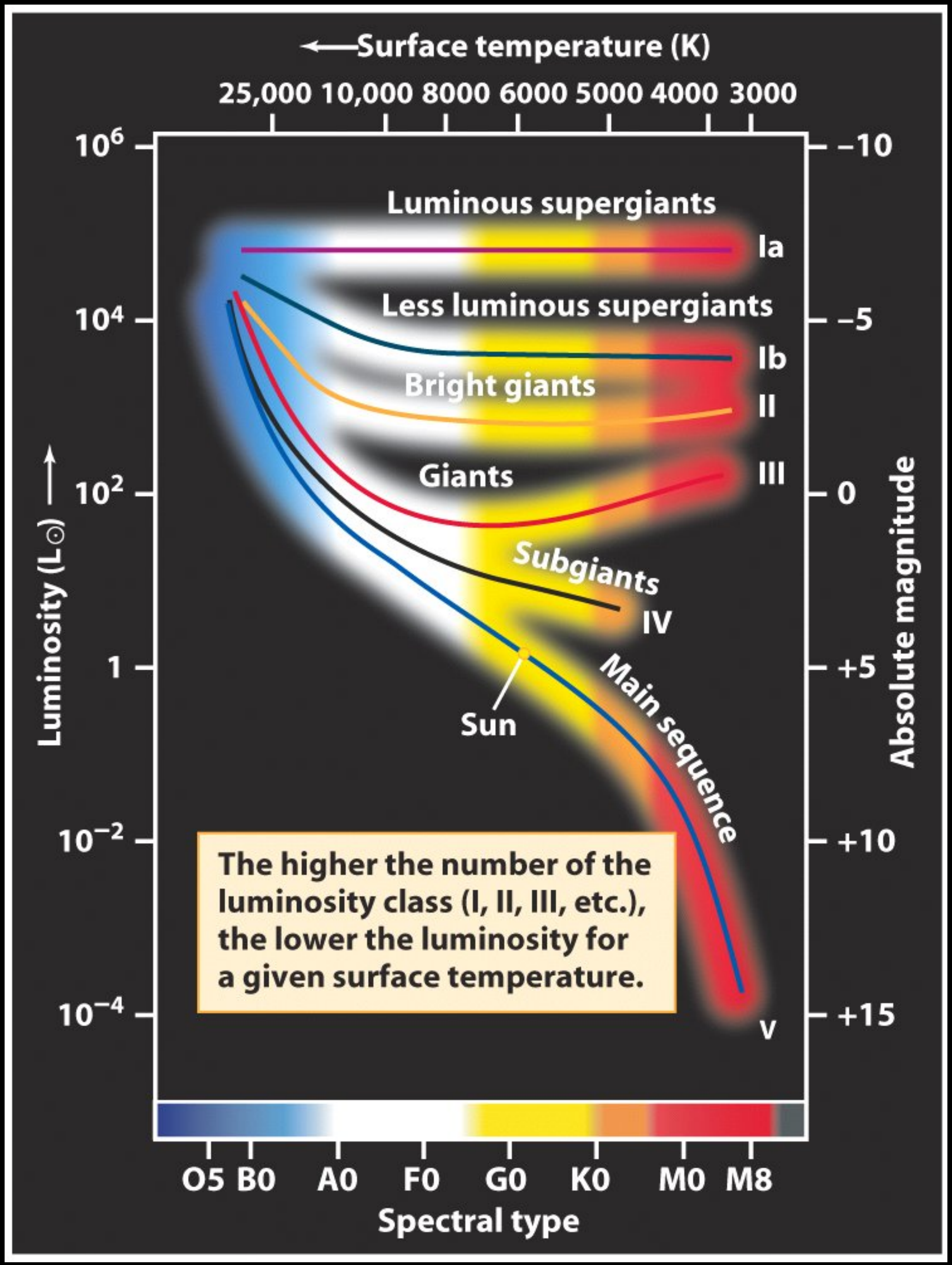
(a) A supergiant star has a low-density, low-pressure atmosphere: its spectrum has narrow absorption lines



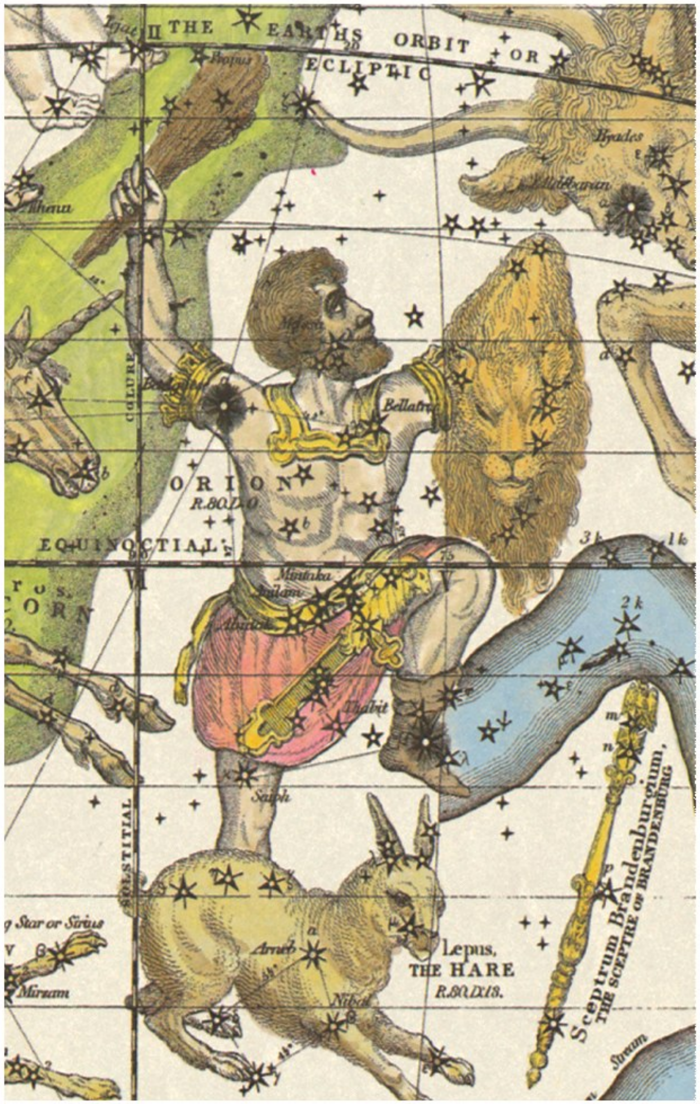
(b) A main-sequence star has a denser, higher-pressure atmosphere: its spectrum has broad absorption lines

By carefully examining a star's spectral lines, astronomers can determine whether that star is a main-sequence star, giant, supergiant, or white dwarf

Using the H-R diagram and the inverse square law, the star's luminosity and distance can be found without measuring its stellar parallax



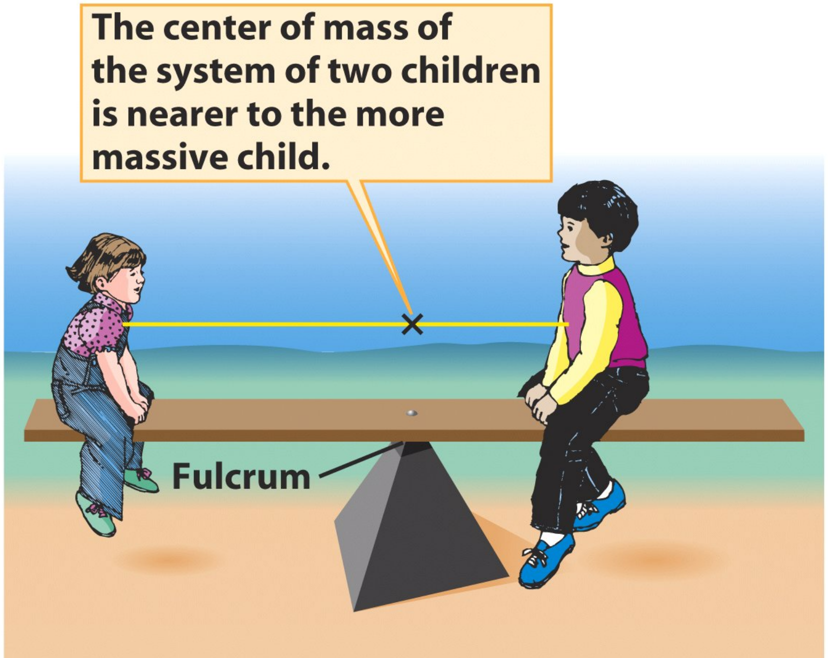
Surface temperature, T



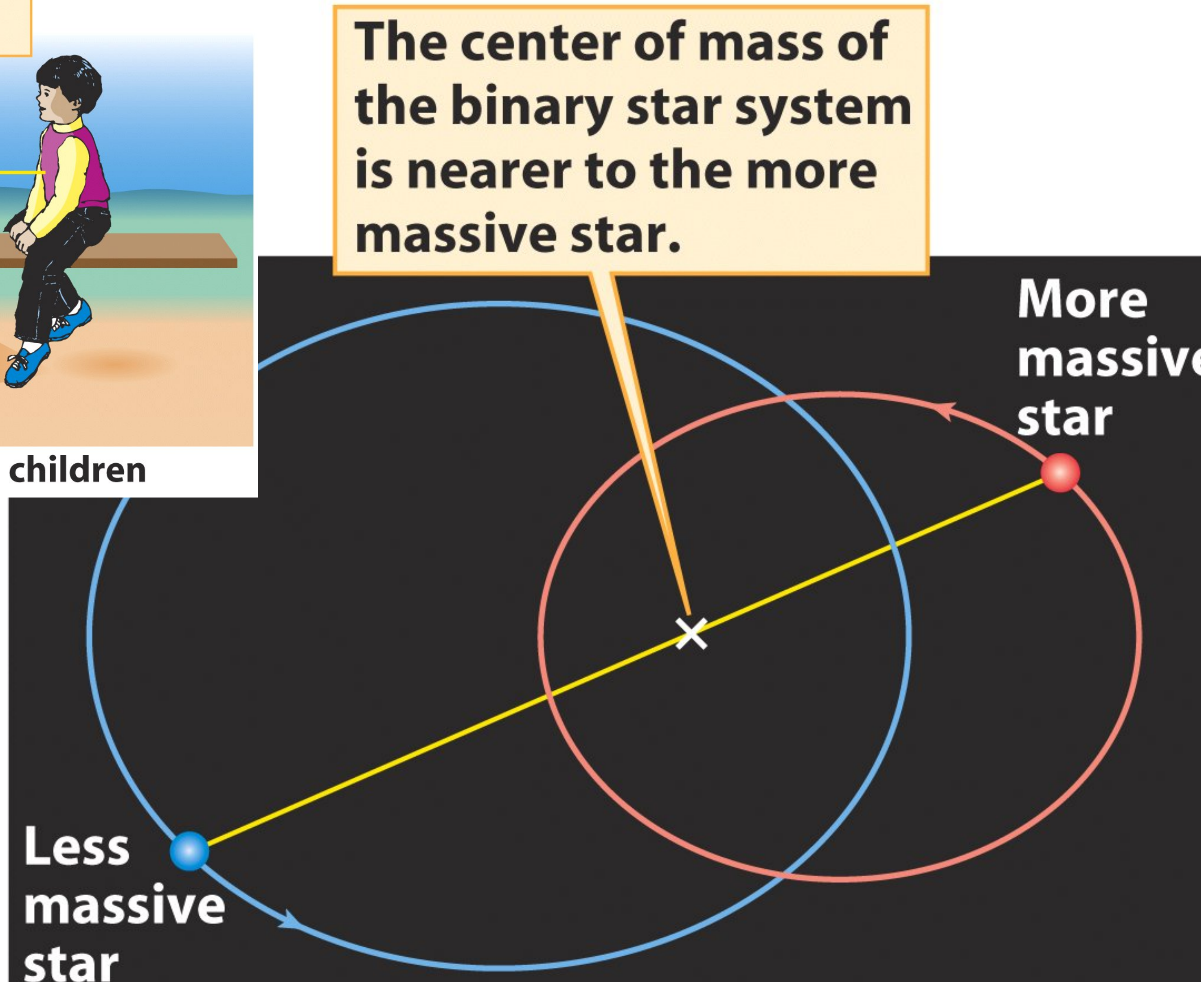
- Ancient peoples looked at the stars and imagined groupings made pictures in the sky and gave them meaning.
- But they were on the wrong track.
- Today we look at the colours and get the surface temperature and the energy flux per m^2.
- With the parallax and apparent brightness we get the luminosity and the radius.
- The life and death of stars

Orion

The mass of stars



A "binary system" of two children



In action!

A binary star system

Binary star systems provide crucial information about stellar masses

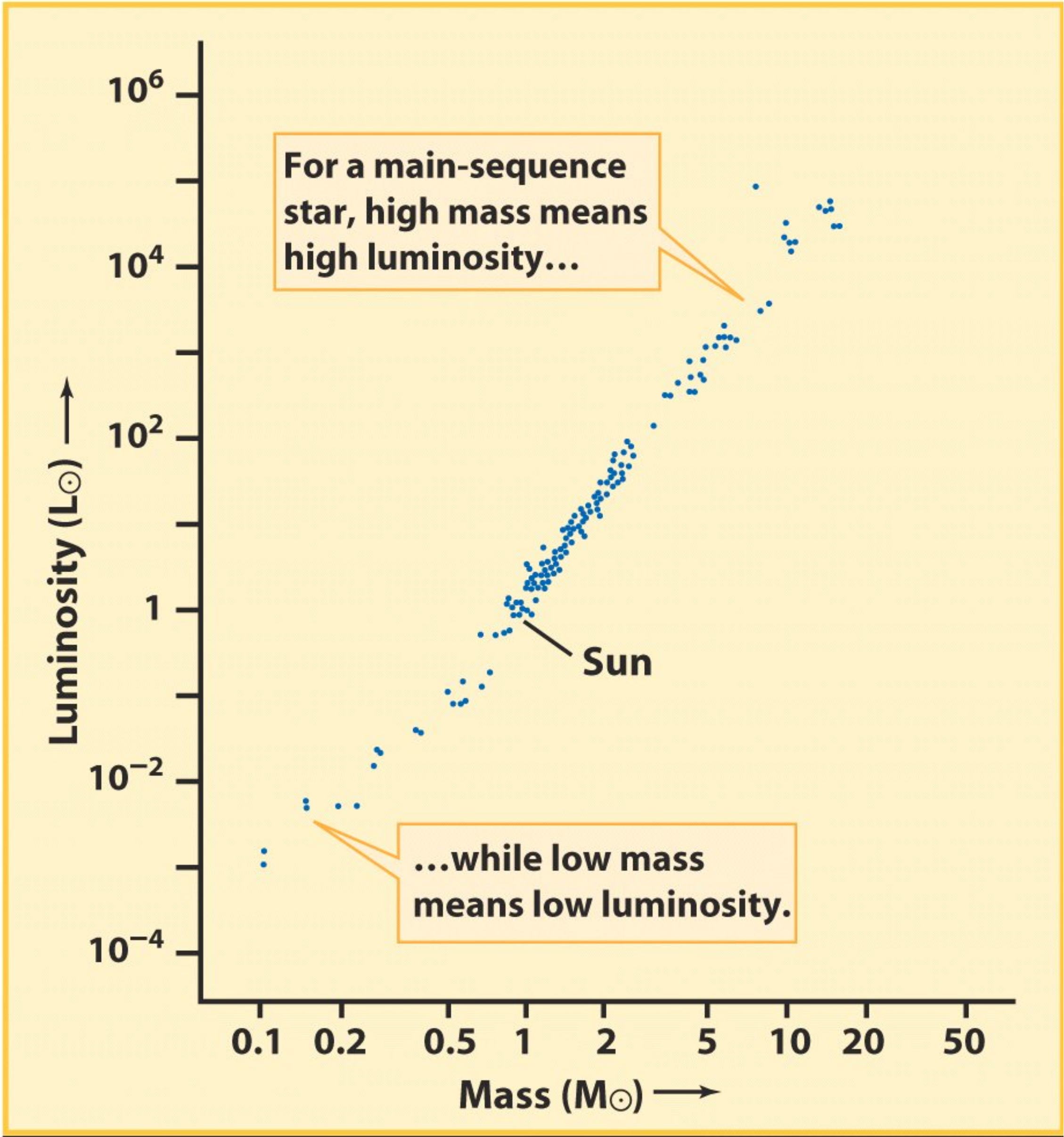
- Binary stars are important because they allow astronomers to determine the masses of the two stars in a binary system
- The masses can be computed from measurements of the orbital period and orbital dimensions of the system

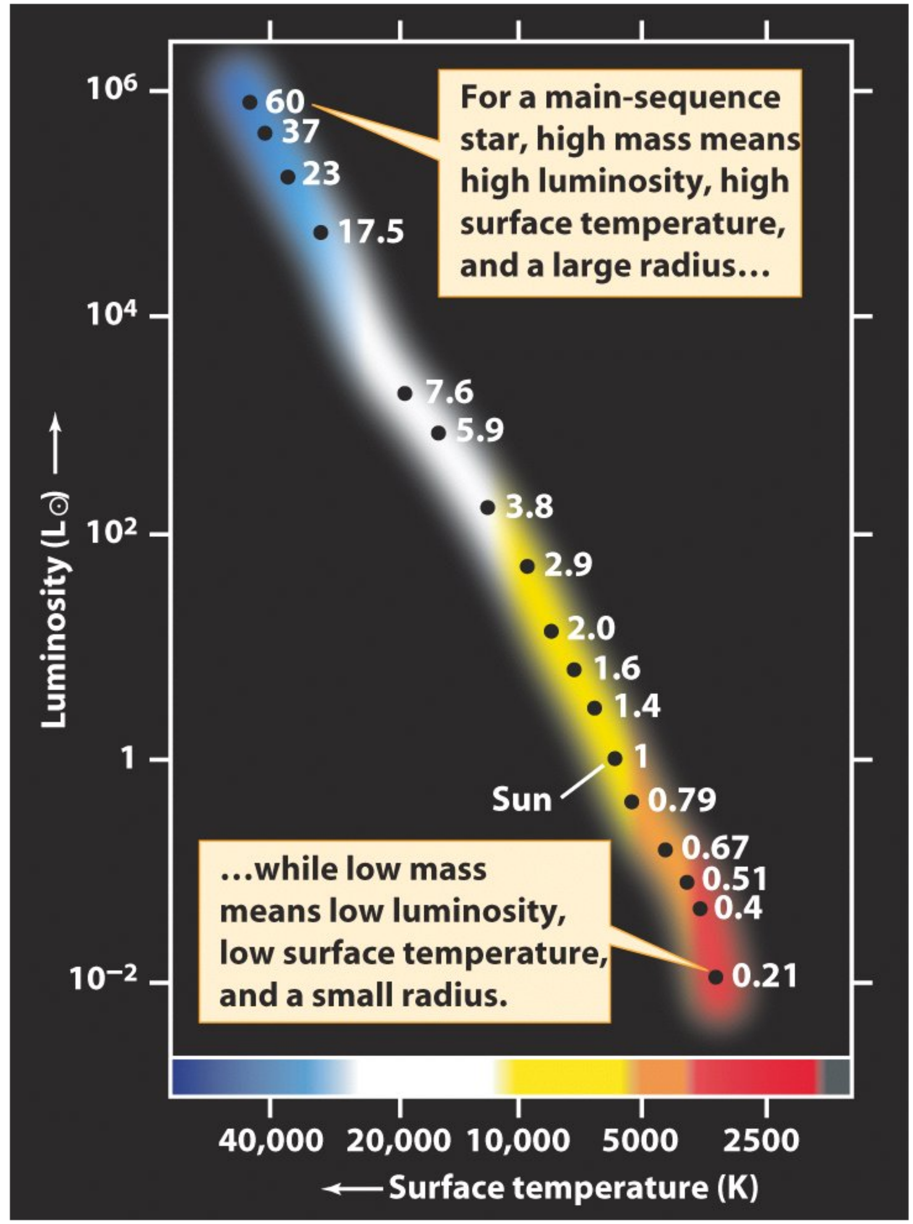
$$M_1 + M_2 = \frac{a^3}{P^2}$$

M_1, M_2 = masses of two stars in binary system, in solar masses

a = semimajor axis of one star's orbit around the other, in AU

P = orbital period, in years



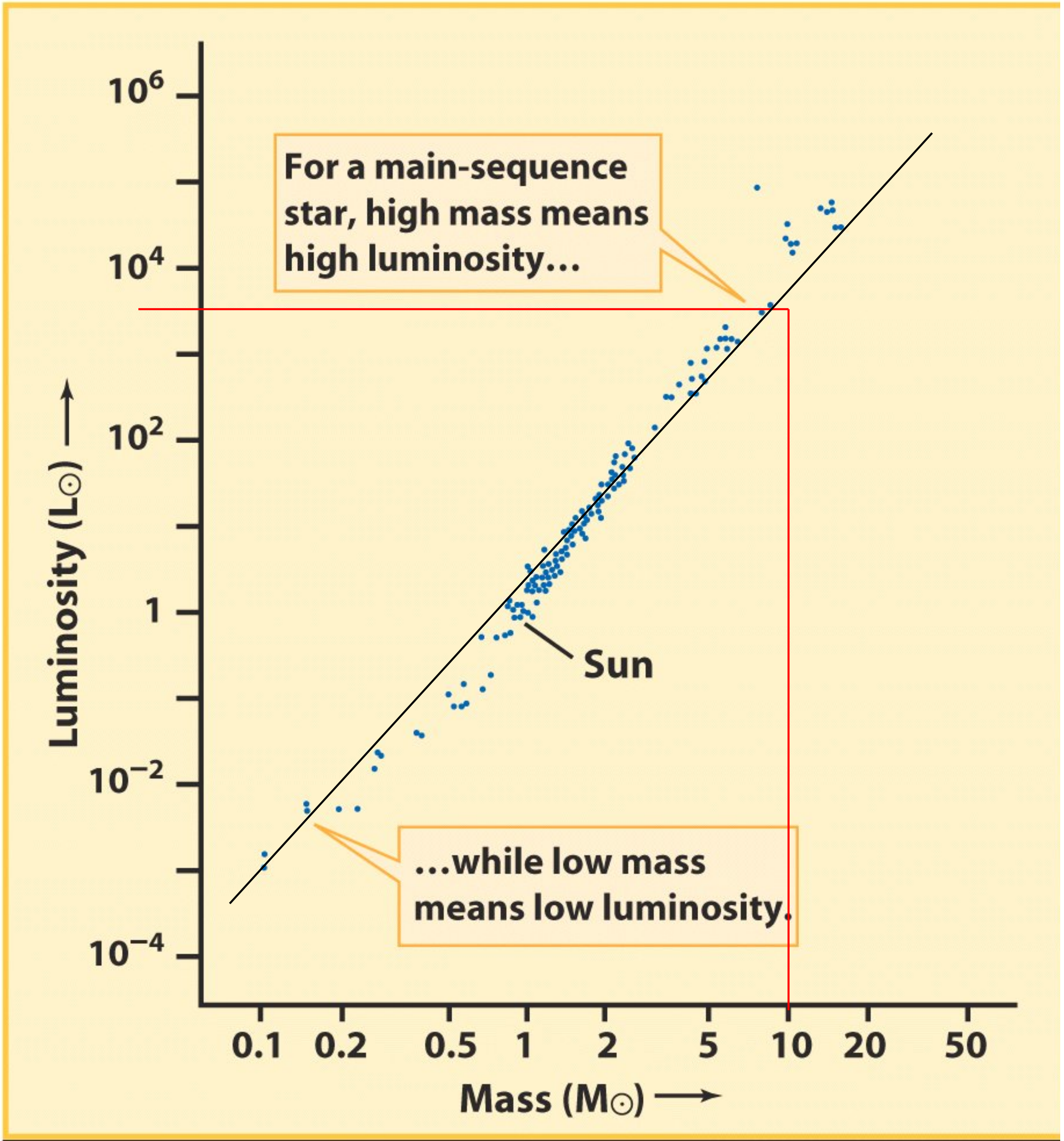


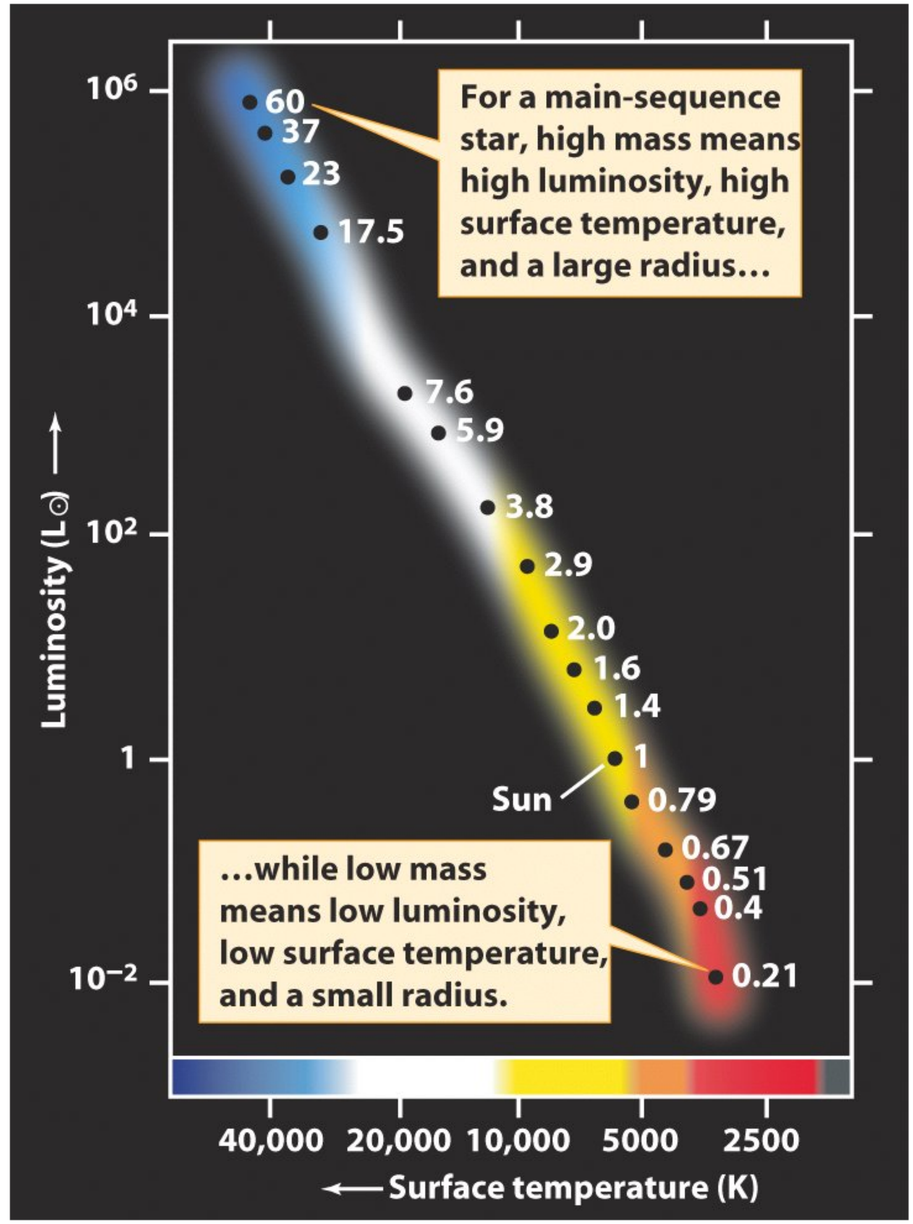
$L/L_{sol} = (M/M_{sol})^{3.5}$

With: $E/E_{sol} = Lt/(L_{sol}\ t_{sol}) = fMc^2/(fM_{sol}\ c^2)$

f: fraction of mass converted into energy

⇨ Lifetime on main sequence: $t/t_{sol} = M/M_{sol})^{-2.5}$





$L/L_{sol} = (M/M_{sol})^{3.5}$ Lifetime on main sequence: $t/t_{sol} = M/M_{sol})^{-2.5}$

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