# Stellar Properties

1. Distance (nearby stars) (17.1)
2. Luminosity/ Absolute mag. (17.2)
3. Apparent brightness/appar. mag. (17.2)
4. Surface Temp./Core Temp. (17.3)
5. Spectral Type & color (17.3)
6. Size (radius)  (17.4)
7. Luminosity Class (17.6, p.456)
8. Mass (17.7,17.8)
9. Radial & Tangential velocity (17.1)
10. Composition (17.3)
11. Distance (far away stars) (17.6)
12. Lifetime & age (17.8)
13. Position on H-R diagram (17.5)

EXERCISE
In groups of 2-3, figure out the following for each property listed to the right:
a) Value for the Sun
b) Range of values for other stars
c) How its measured
d) Theory behind interpretation of measurement.

# Table 17-5
# Measuring the Stars

## TABLE 17.5   Measuring the Stars

| Stellar Property | Measurement Technique | "Known" Quantity | Measured Quantity | Theory Applied | Section |
|---|---|---|---|---|---|
| Distance | stellar parallax | astronomical unit | parallactic angle | elementary geometry | 17.1 |
| Distance - far | spectroscopic parallax | main sequence | spectral type apparent magnitude | inverse-square law | 17.6 |
| Radial velocity | spectroscopy | speed of light atomic spectra | spectral lines | Doppler effect | 17.1 |
| Transverse velocity | astrometry | distance | proper motion | elementary geometry | 17.1 |
| Luminosity | photometry | distance main sequence | apparent magnitude spectral type | inverse square law | 17.2 17.6 |
| Temperature | photometry spectroscopy | | color spectral type | blackbody law atomic physics | 17.3 17.3 |
| Radius | direct indirect | distance | angular size luminosity temperature | elementary geometry radius–luminosity– temperature relationship | 17.4 17.4 |
| Composition | spectroscopy | | spectrum | atomic physics | 17.3 |
| Mass | observations of binary stars | (distance) | binary period binary orbit orbital velocity | Newtonian gravity and dynamics | 17.7 |

# Table 17-6
## Key Properties of Some Well-Known Main-Sequence Stars

| Star | Spectral Type | Mass, $M$ (Solar Masses) | Central Temperature ($10^6$ K) | Luminosity, $L$ (Solar Luminosities) | Estimated Lifetime ($M/L$) ($10^6$ years) |
|---|---|---|---|---|---|
| Spica B* | B2V | 6.8 | 25 | 800 | 90 |
| Vega | A0V | 2.6 | 21 | 50 | 500 |
| Sirius | A1V | 2.1 | 20 | 22 | 1000 |
| Alpha Centauri | G2V | 1.1 | 17 | 1.6 | 7000 |
| Sun | G2V | 1.0 | 15 | 1.0 | 10,000 |
| Proxima Centauri | M5V | 0.1 | 0.6 | 0.00006 | 16,000,000 |

*The "star" Spica is, in fact, a binary system comprising a B1III giant primary (Spica A) and a B2V main-sequence secondary (Spica B).

# 1. Distances to nearby stars

a) Value for Sun.*

  93,000,000 miles or 150,000,000 km.

  This is only $1.5 \times 10^{-5}$ LY.

b) Range of values for other stars.

  Closest: 4.3 LY for Proxima Centauri. (4.22 LY)

  Farthest: Stars exist in galaxies which have distances out to the edge of the observable universe (about 10,000,000,000 LY).

  However, the technique of "Stellar Parallax" is limited by the resolution of our imagers. It can only be measured out to 200 pc (600 LY) from the ground, The Hipparcos satellite "measured parallaxes to over 200 pc, encompassing over a million stars." Hipparcos measured 118,000 stars with a median precision of +-1 mas corresponding distances to 3300 LY, another million stars were measured with lower precision.
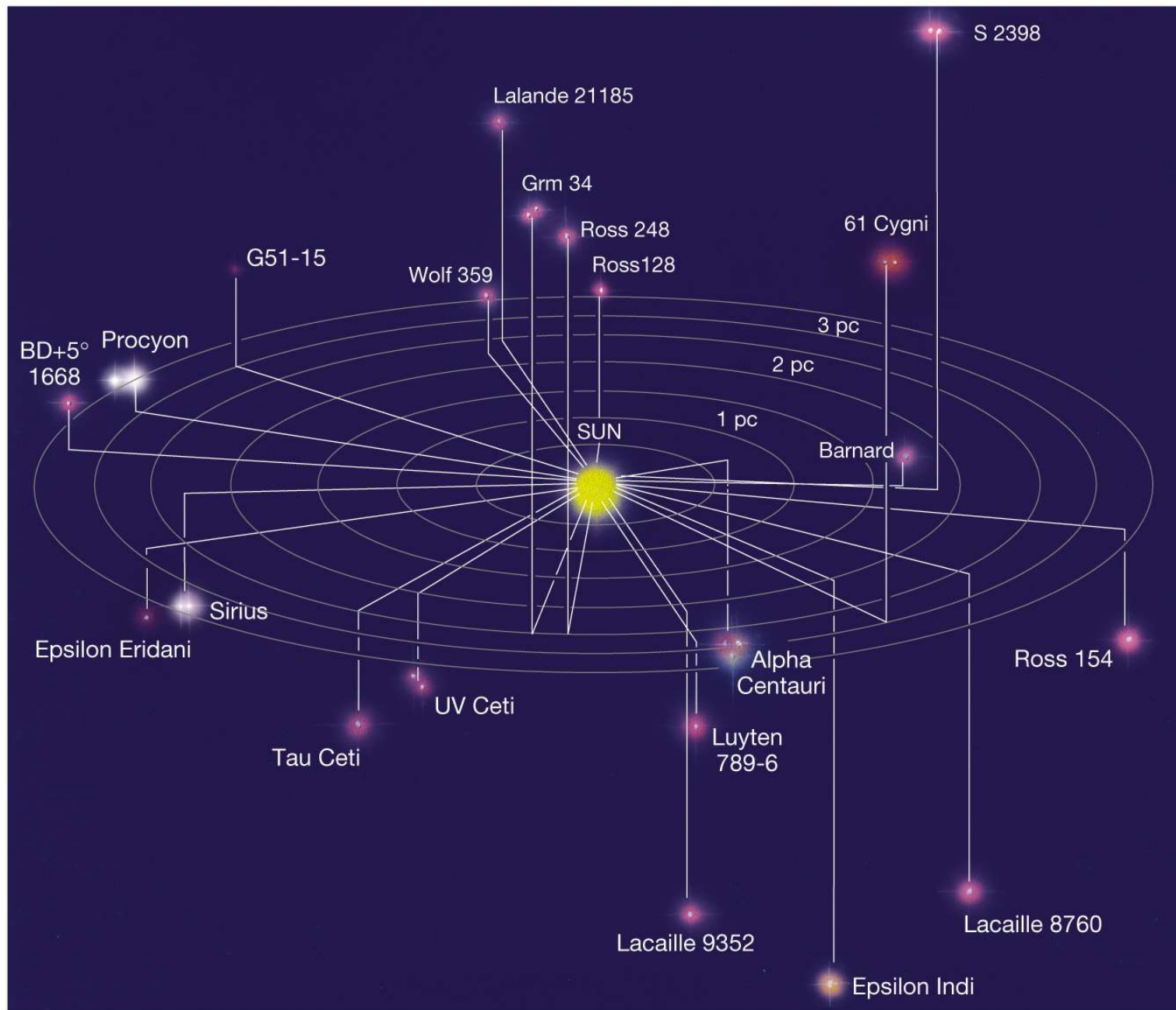
c) How its measured

  Image a star (on film or CCD) at least two times from two positions as far apart as possible. The more images at different positions, the better. A nearby star will appear to move relative to background stars (or an absolute coordinate system).
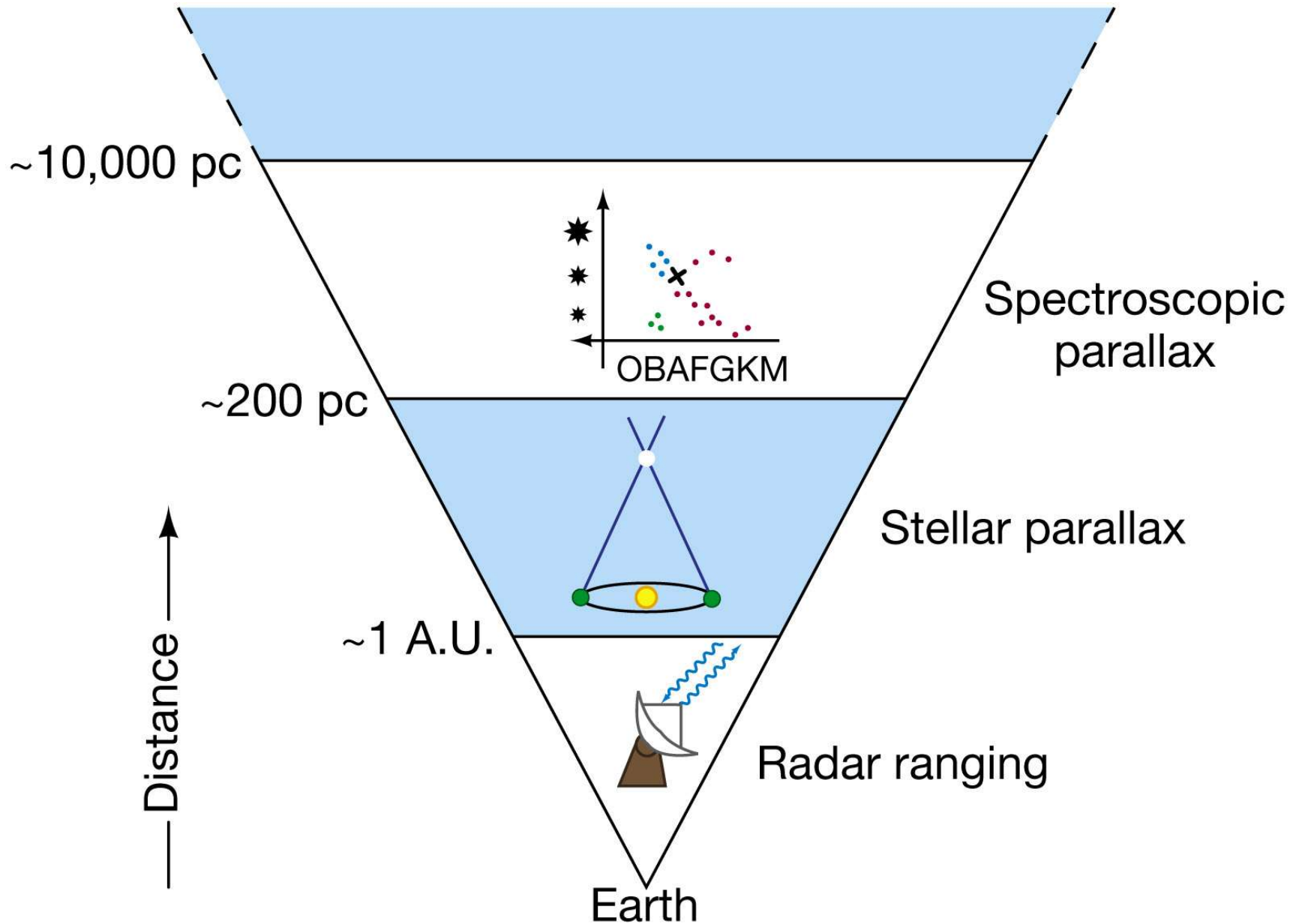
d) Theory behind interpretation of measurement.

  The theory is simple geometry, not physics. $D = 1/\pi$ where D is distance (in parsecs) and $\pi$ is the parallax angle (in arcseconds).

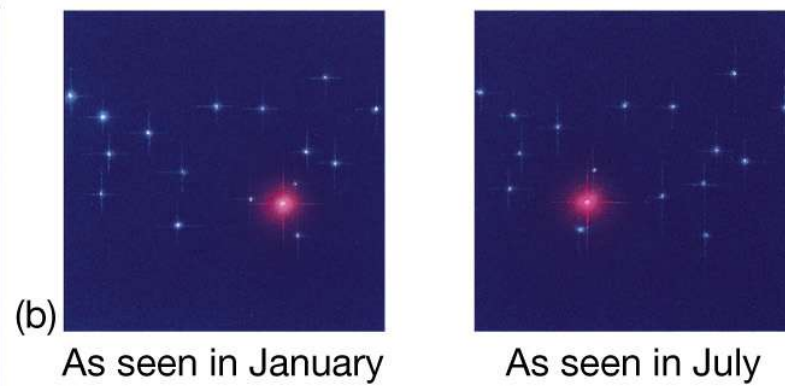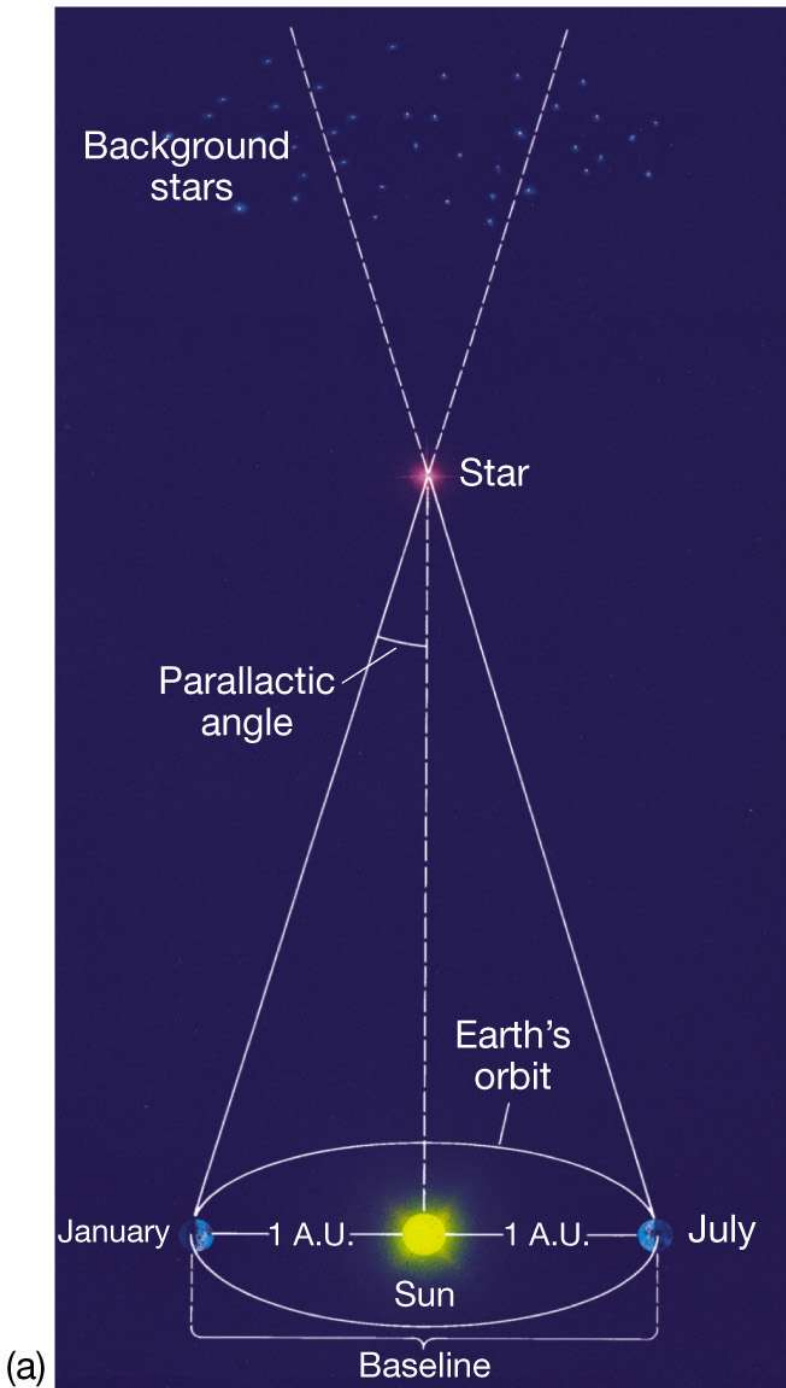* green text means information from Astronomy Today 5th Ed.

# Figure 17-2: The Solar Neighborhood

# Figure 17-17
## Stellar Distances



~10,000 pc

OBAFGKM

Spectroscopic parallax

~200 pc

Stellar parallax

~1 A.U.

Radar ranging

Distance

Earth

(b) As seen in January   As seen in July

**Figure 17-1**
**Stellar Parallax**

Note that the parallax (here "parallactic angle") is ½ of the angular shift of the star between January and July

# Discovery 17-2
## The *Hipparcos* Mission
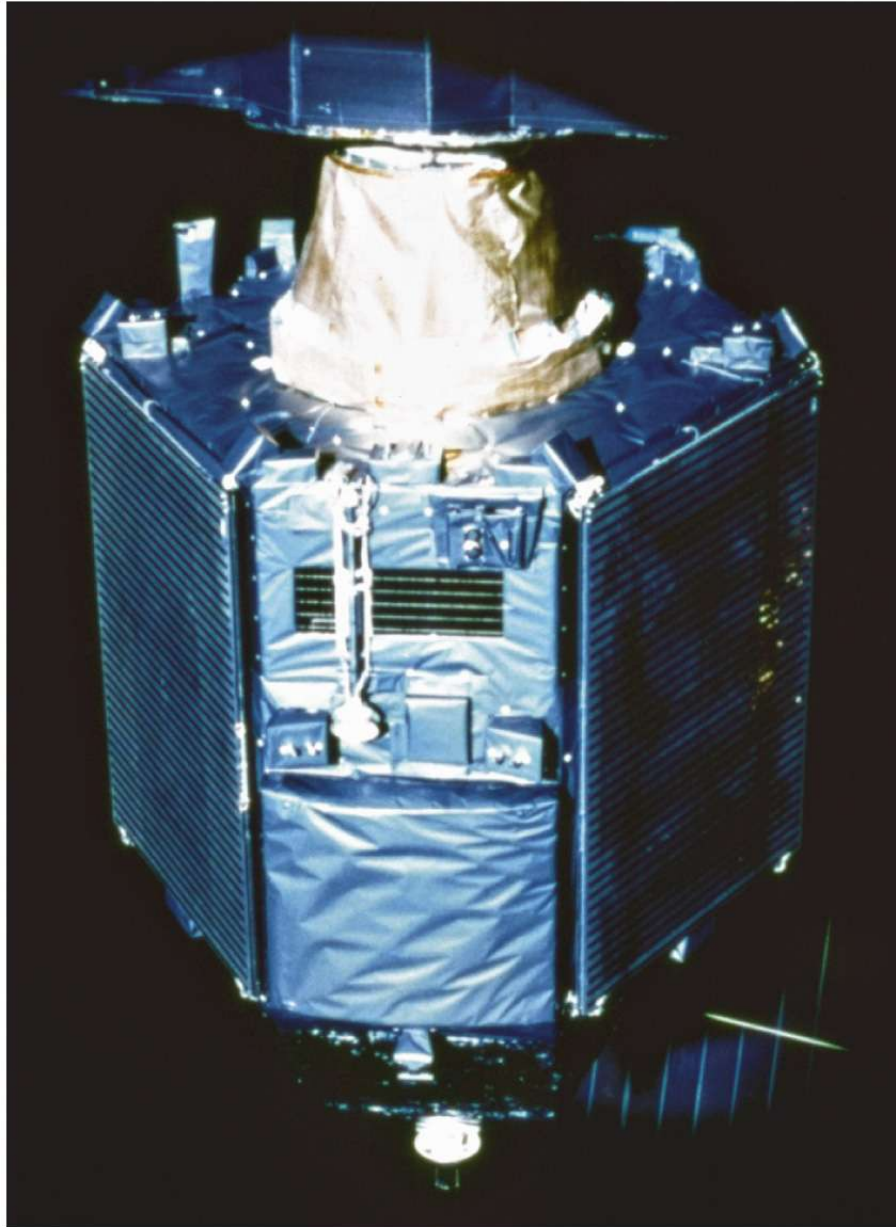
# 2. Luminosity and Absolute Magnitude

a) Values for the Sun

$L$=3.9x10$^{26}$ W = 1 Lsun

Msun = 4.83

b) Range of values for other stars

M-type stars have the lowest L among main sequence stars, $L \sim$ .005 Lsun

O-type stars have the largest L among main sequence stars, $L \sim 10^5$ Lsun

Non-main sequence stars can be fainter (white dwarfs, neutron stars) and brighter (blue supergiants, novae, supernovae).

c) How its measured
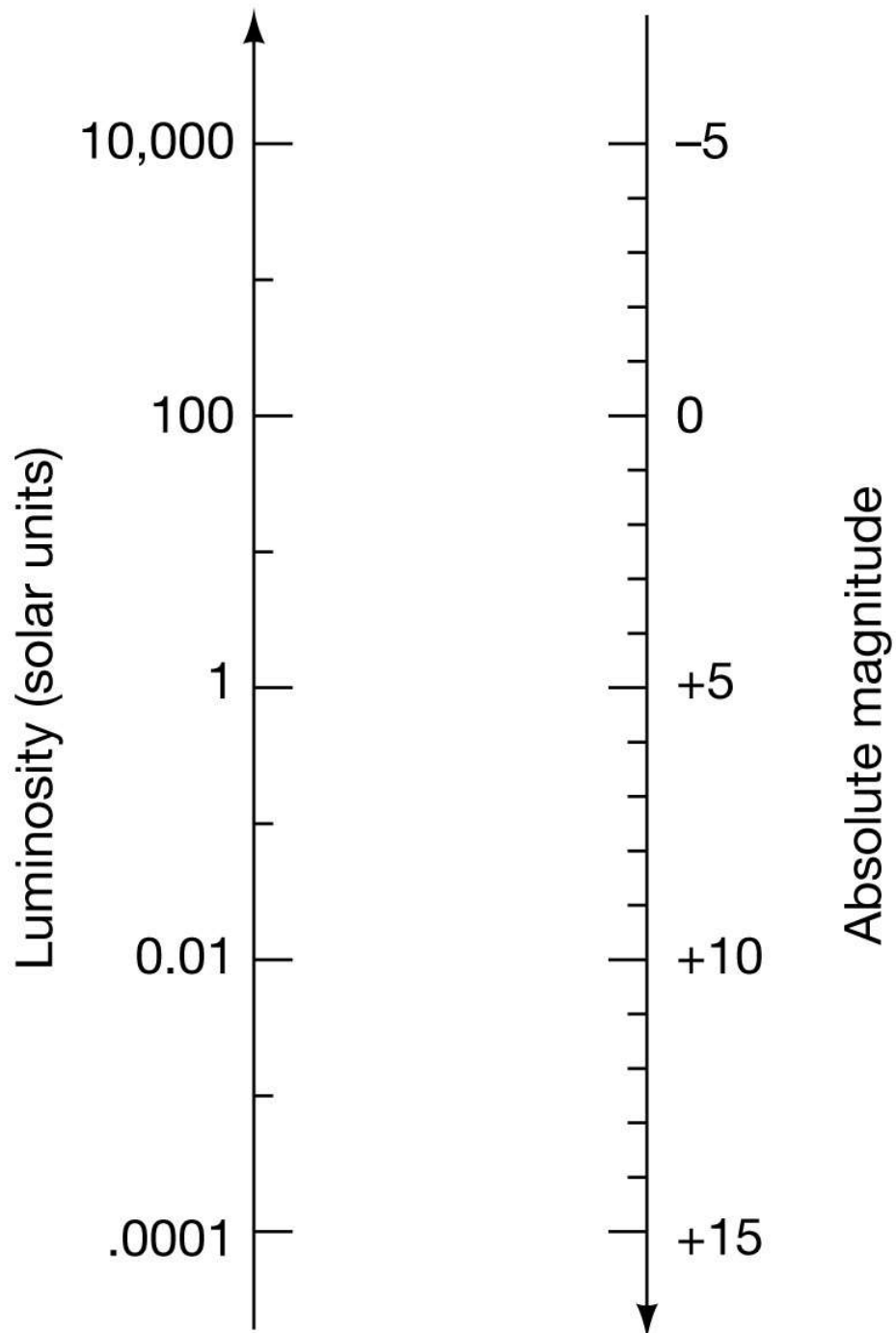
Use photometry to get the apparent brightness (flux or $m$), then get a distance from parallax. Solve for distance (see equation below).

OR take a spectrum which gives the spectral type and luminosity class. This allows one to roughly locate the star on the H-R diagram. Read off $L$.
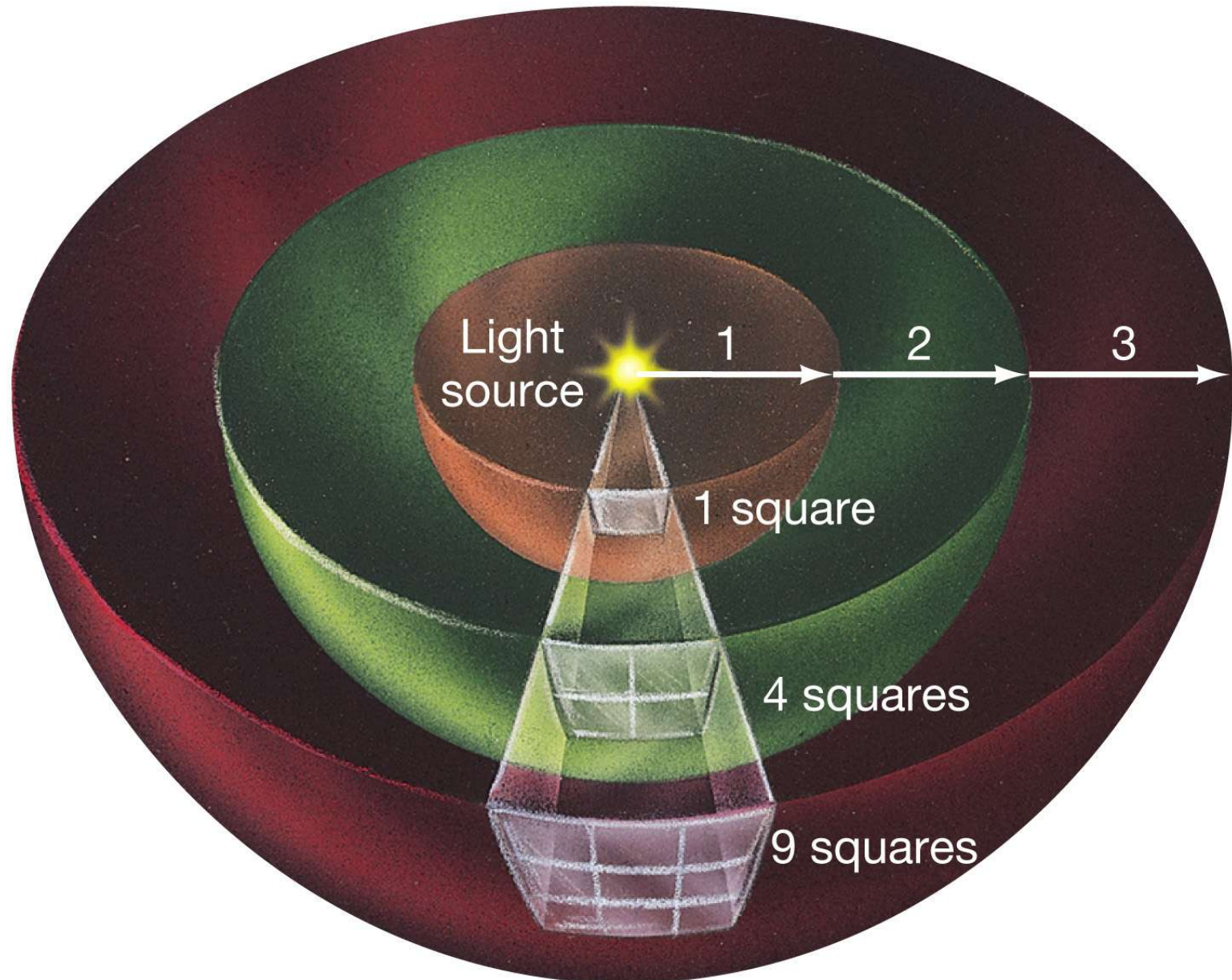
d) Theory behind interpretation of measurement.

Luminosity is the total amount of light energy leaving the object – in all directions! To find $L$, measure the flux at a distance, $d$, and then multiply the flux by the surface area of a sphere of radius $d$.
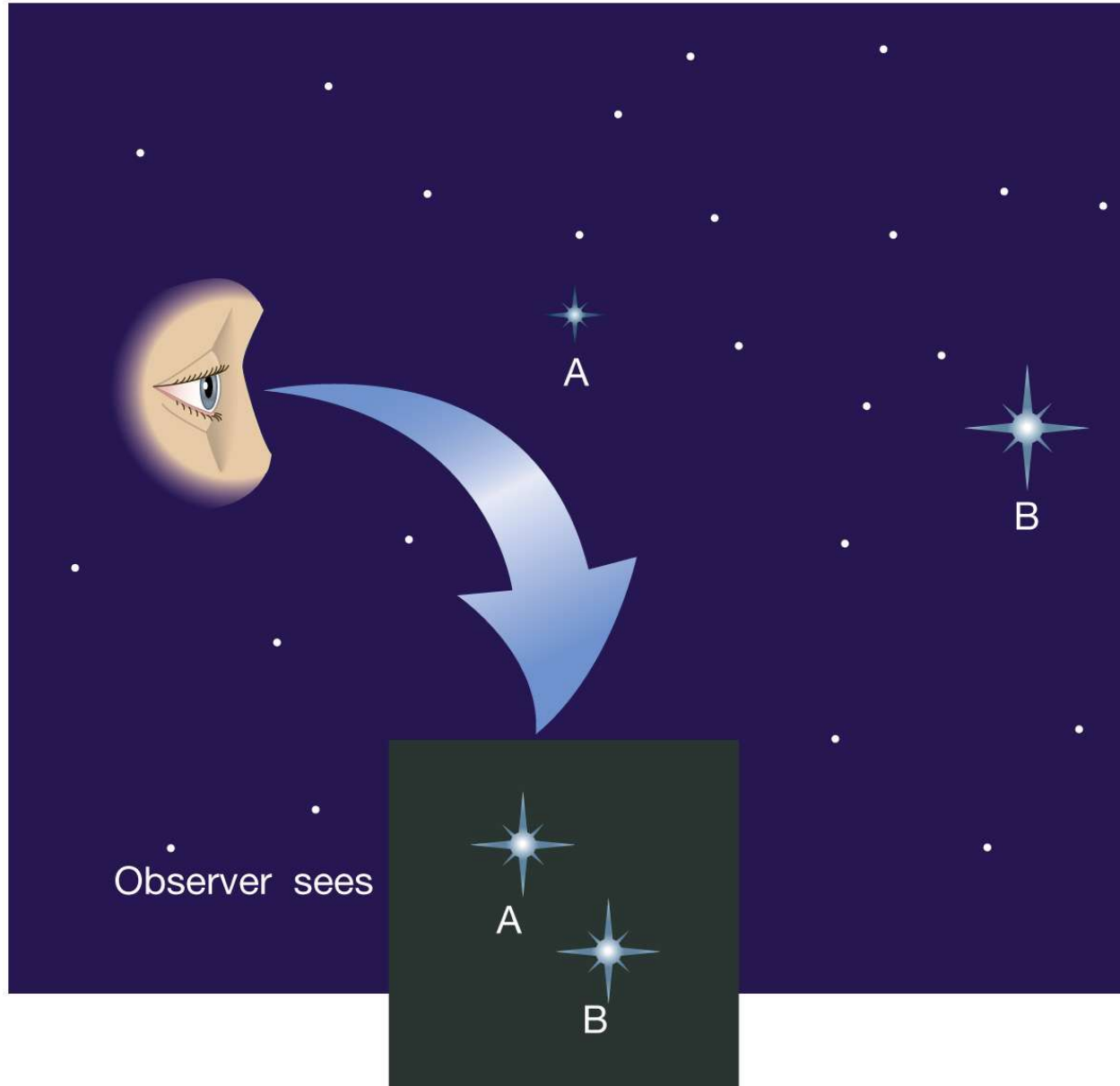
$$L = 4\pi d^2 (flux)$$

Luminosity (solar units)

10,000

100

1

0.01

.0001

Absolute magnitude

−5

0

+5

+10

+15

**More Precisely 17-1**
**More on the Magnitude Scale**

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**Figure 17-5**
**Inverse-Square Law**

Light source

1    2    3

1 square

4 squares

9 squares

# Figure 17-6
## Luminosity

# Apparent brightness / apparent magnitude

a) Values for the Sun
   $m = -26.7$
b) Range of values for other stars
   Sun is brightest (-26.7), we can observe others as faint as $m=+30.0$.
   Next brightest star is -1.5 (Sirius).
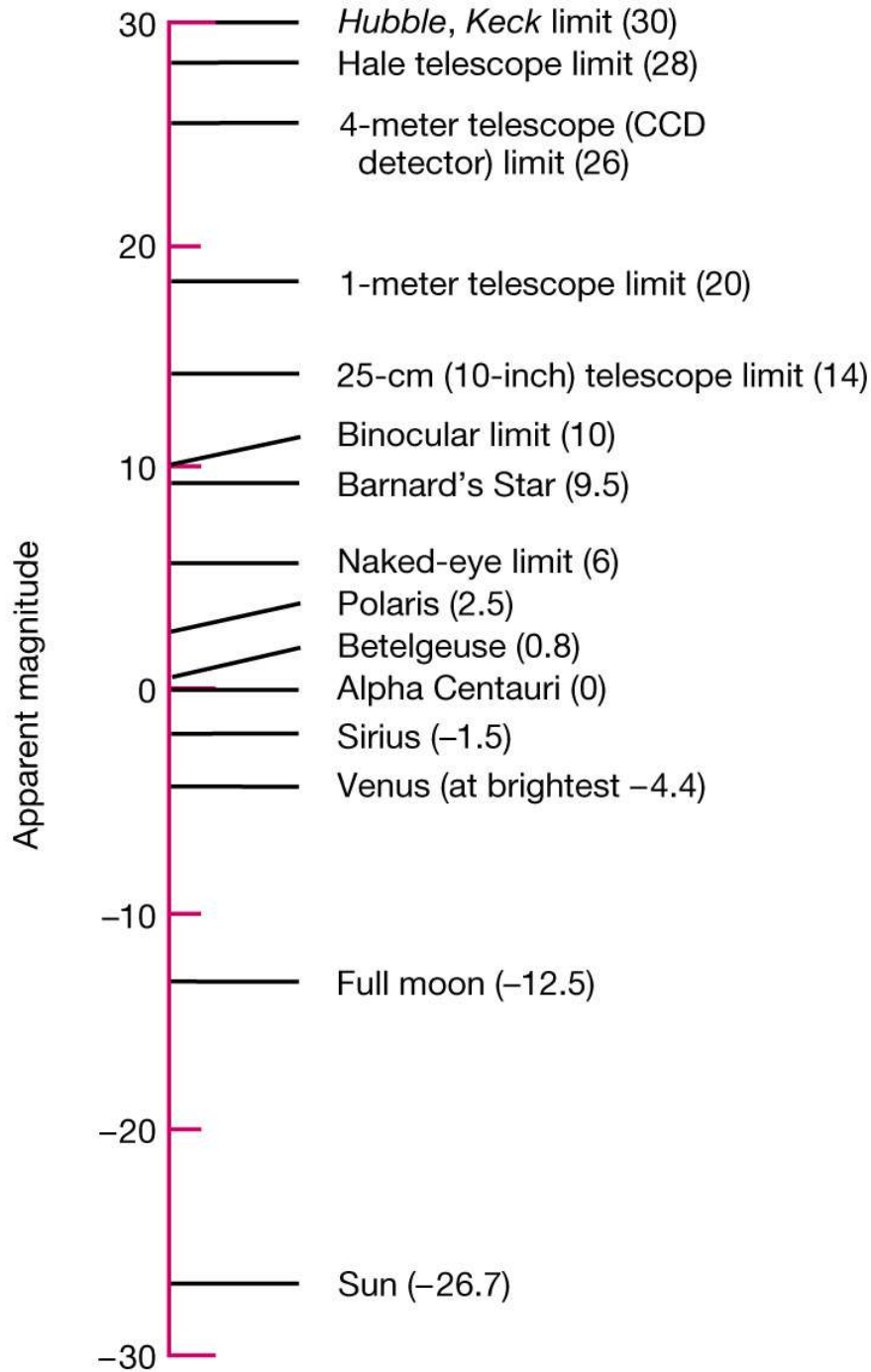   Planets can appear even brighter, and the Moon is -12.5.
c) How its measured
   Use photometry to get a flux (counts per second). Apparent magnitude is then given by m = -2.5 log (flux/reference flux).

d) Theory behind interpretation of measurement.
   The counts that we receive in a detector tell us the intensity or flux of photons at the Earth.

**Figure 17-7**
**Apparent Magnitude**

The vertical scale shows apparent magnitude with the following markers:

- Hubble, Keck limit (30)
- Hale telescope limit (28)
- 4-meter telescope (CCD detector) limit (26)
- 1-meter telescope limit (20)
- 25-cm (10-inch) telescope limit (14)
- Binocular limit (10)
- Barnard's Star (9.5)
- Naked-eye limit (6)
- Polaris (2.5)
- Betelgeuse (0.8)
- Alpha Centauri (0)
- Sirius (−1.5)
- Venus (at brightest −4.4)
- Full moon (−12.5)
- Sun (−26.7)

Apparent magnitude

# Surface and core temperature

a) Values for the Sun

   *Tcore= 15x10$^6$ K*

   *Tsurface= 5800 K*

b) Range of values for other stars

   *Tsurface* ranges from 3000 to 50000 K  for main sequence stars.

   Tcore ranges from 9x10$^6$ to 25x10$^6$.

c) How its measured

   Tsurf:  a) use multi-color photometry (ie. image through color filters).  The colors correlate with surface temperature (blue=hot, red=cool). b) take a spectrum and measure the strengths of many different absorption lines.
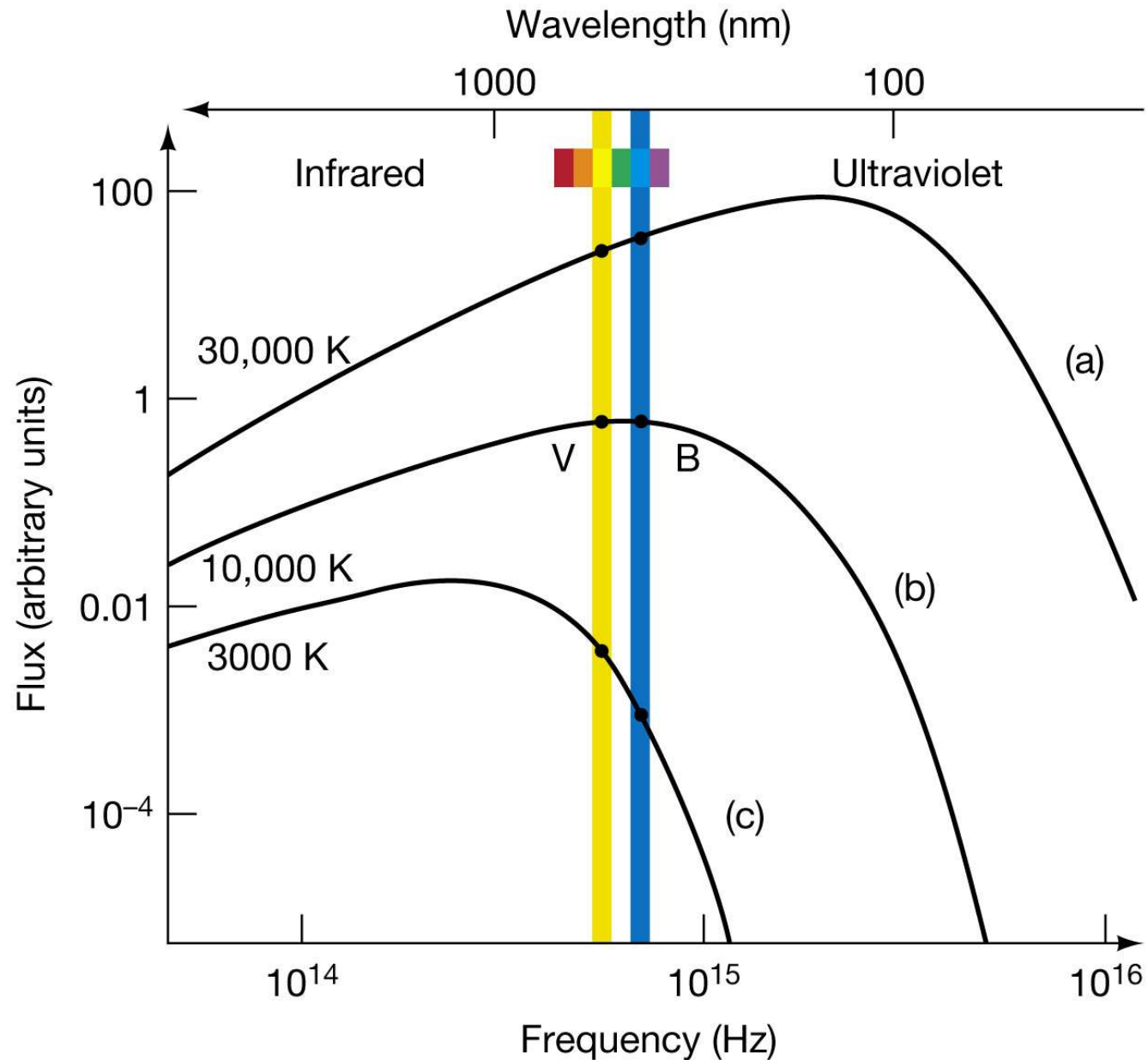
   Tcore: MANY observables used:  radius, surface temp, surface density, total mass (from planet orbits), total luminosity. This information is fed into a computer that uses laws of physics to make a stellar model.  The model will include temperature at the core.
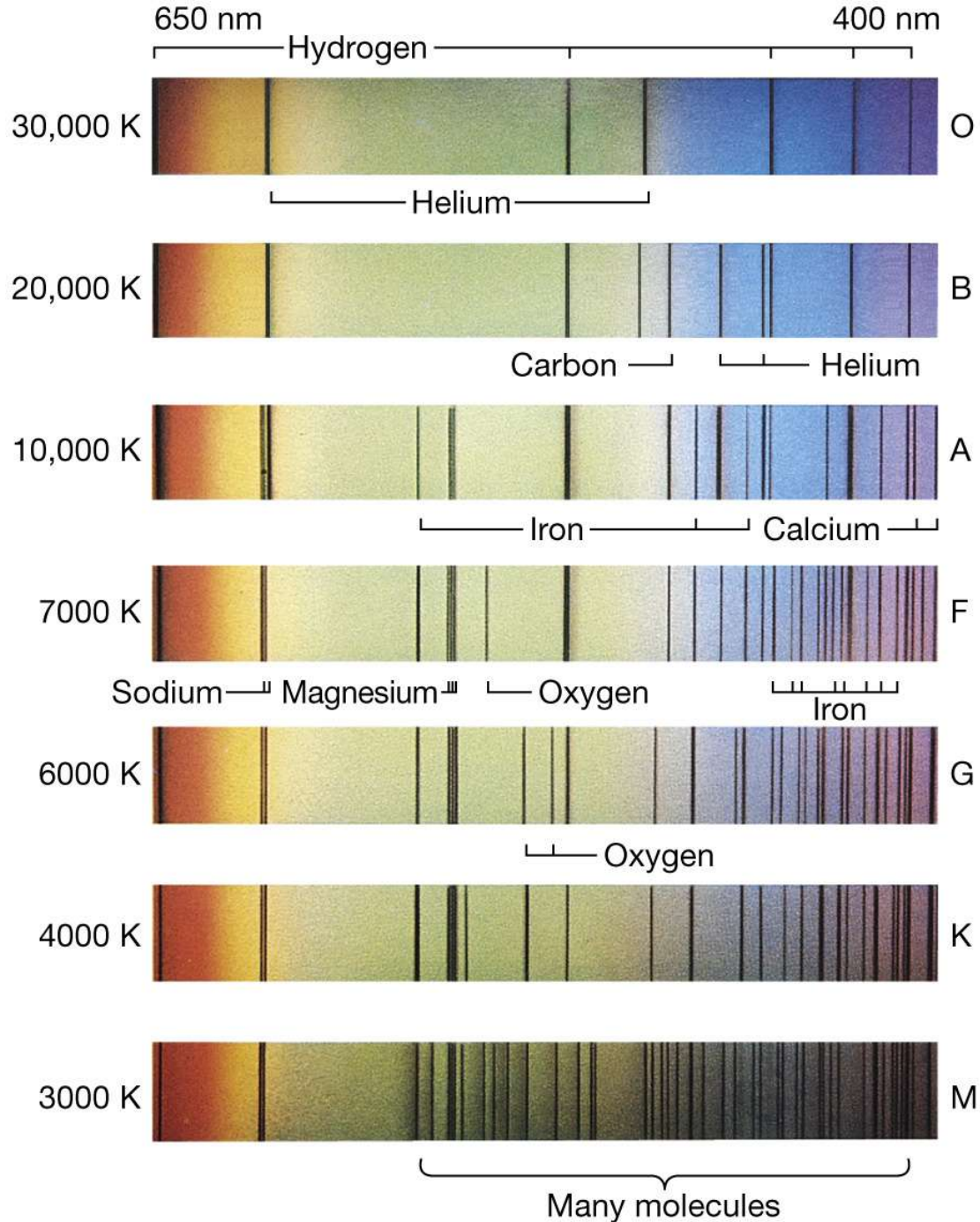
d) Theory behind interpretation of measurement.

   Tsurf: a) blackbody law – for a blackbody, each temperature produces a unique continuous spectrum with a unique peak wavelength (λmax).   The shape of this spectrum across the filter bandwidths determines the colors measured.  b) atomic physics – the strength of absorption lines created by a given element depend on the gas temperature.

   Tcore: structural equations (like hydrostatic equilibrium), and nuclear physics

# Figure 17-9
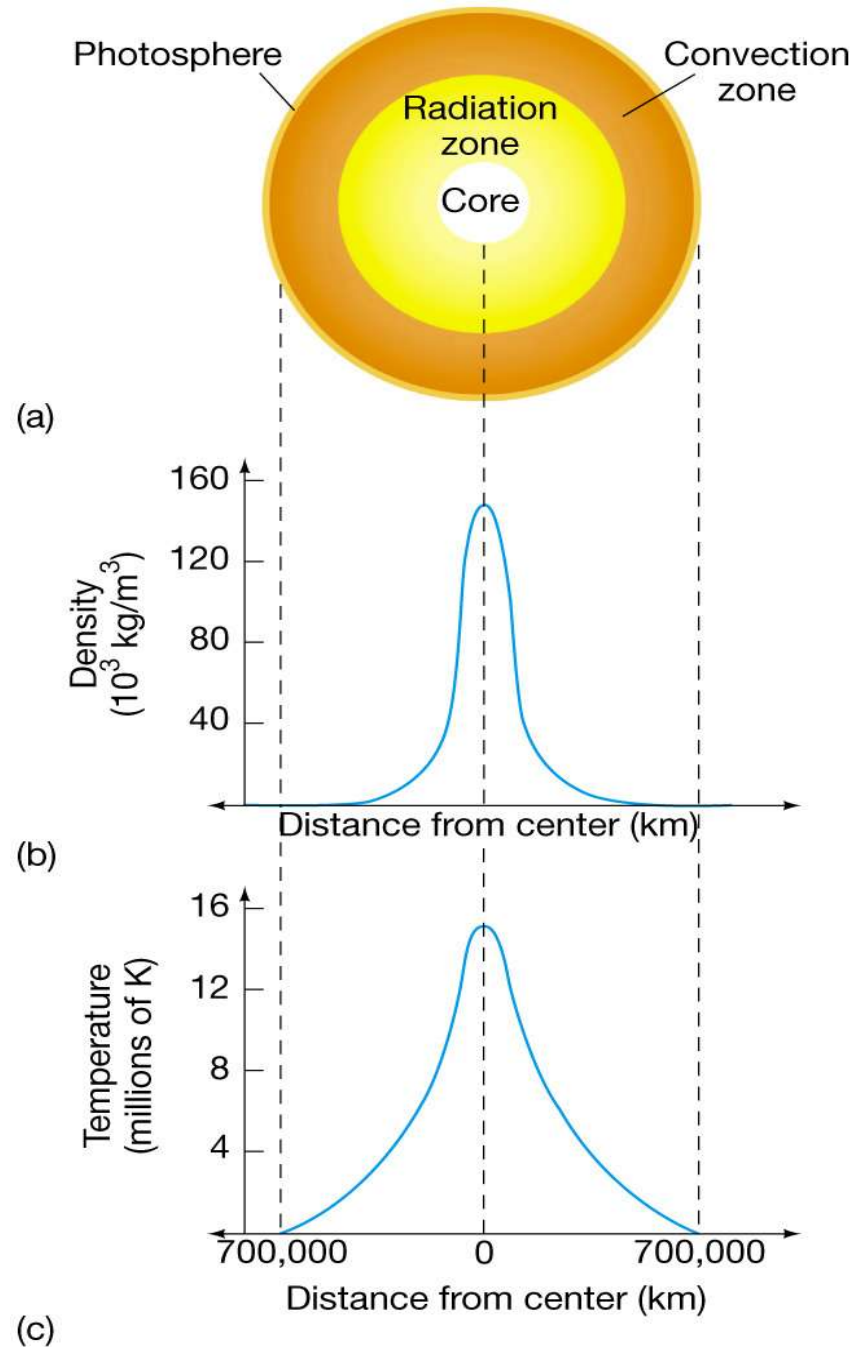# Blackbody Curve

**Figure 17-10
Stellar Spectra**

650 nm      400 nm

Hydrogen

30,000 K    O

Helium

20,000 K    B

Carbon    Helium

10,000 K    A

Iron    Calcium

7000 K    F

Sodium — Magnesium — Oxygen — Iron

6000 K    G

Oxygen

4000 K    K

3000 K    M

Many molecules

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Core temperature is found by creating a stellar model. You observe things like radius, total mass, and luminosity, and these will constrain the model. The model requires several physics equations and knowledge of the temperature and density required for nuclear fusion.

Photosphere

Convection zone

Radiation zone

Core

(a)

Density (10³ kg/m³)

160
120
80
40

Distance from center (km)

(b)

Temperature (millions of K)

16
12
8
4

700,000            0            700,000

Distance from center (km)

(c)

# Table 17-1
## Stellar Colors and Temperatures

| TABLE 17.1 | Stellar Colors and Temperatures | | |
|---|---|---|---|
| **$\dfrac{\text{B flux}}{\text{V flux}}$** | **Approximate Surface Temperature (K)** | **Color** | **Familiar Examples** |
| 1.3 | 30,000 | blue-violet | Mintaka ($\delta$ Orionis) |
| 1.2 | 20,000 | blue | Rigel |
| 1.00 | 10,000 | white | Vega, Sirius |
| 0.72 | 7000 | yellow-white | Canopus |
| 0.55 | 6000 | yellow | Sun, Alpha Centauri |
| 0.33 | 4000 | orange | Arcturus, Aldebaran |
| 0.21 | 3000 | red | Betelgeuse, Barnard's Star |

# Spectral types and colors

a) Values for the Sun

Spectral Type = G2 V

Color = yellow-white (qualitatively), B/V = 0.55 (quantitatively). (B-V=0.65 actual color index).

b) Range of values for other stars

Spectral types range from 0 to M

Colors range from red to blue (qualitatively), B/V ranges from 0.2-1.3.

(B-V = -0.4 - 2.1)

c) How it's measured

Spectral Types: spectroscopy, measure absorption line strengths

Colors:  use multi-color photometry (ie. record images or counts through color filters).

d) Theory behind interpretation of measurement.

Spectral Types: no theory, just an arbitrary classification scheme.  (However, the spectral types have been arranged in order of decreasing surface temperature.)

Colors: qualitative colors are explained with the physiology of the eye (different cone cells in the retina respond to different frequencies of light).  Quantitative colors, namely B/V, are measured with photometry.  The ``theory" behind photometry is that counts in linear light detectors are proportional to the flux of light. Also, that color filters allow a narrow range of frequencies to pass so that counts are proportional to light we call "blue", "red", "UV", etc.
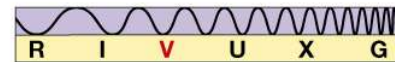
# Figure 17-8
# Star Colors



(a)

(b)

R  I  V  U  X  G

Copyright © 2005 Pearson Prentice Hall, Inc.
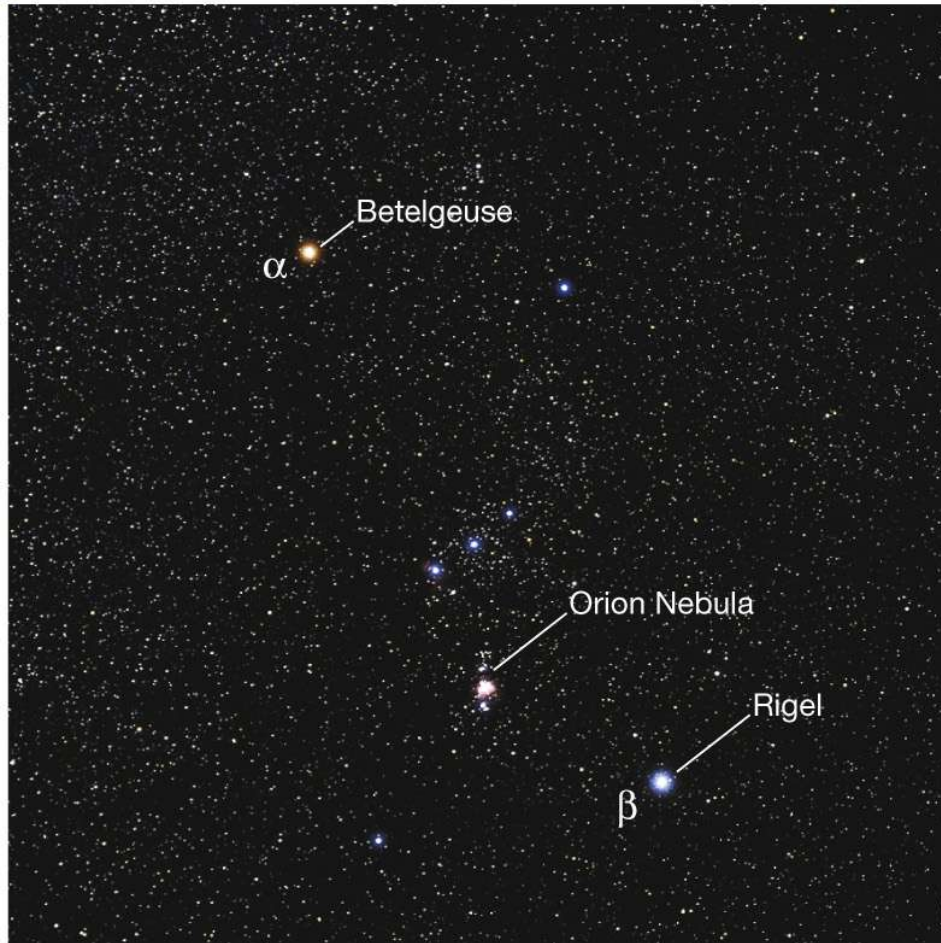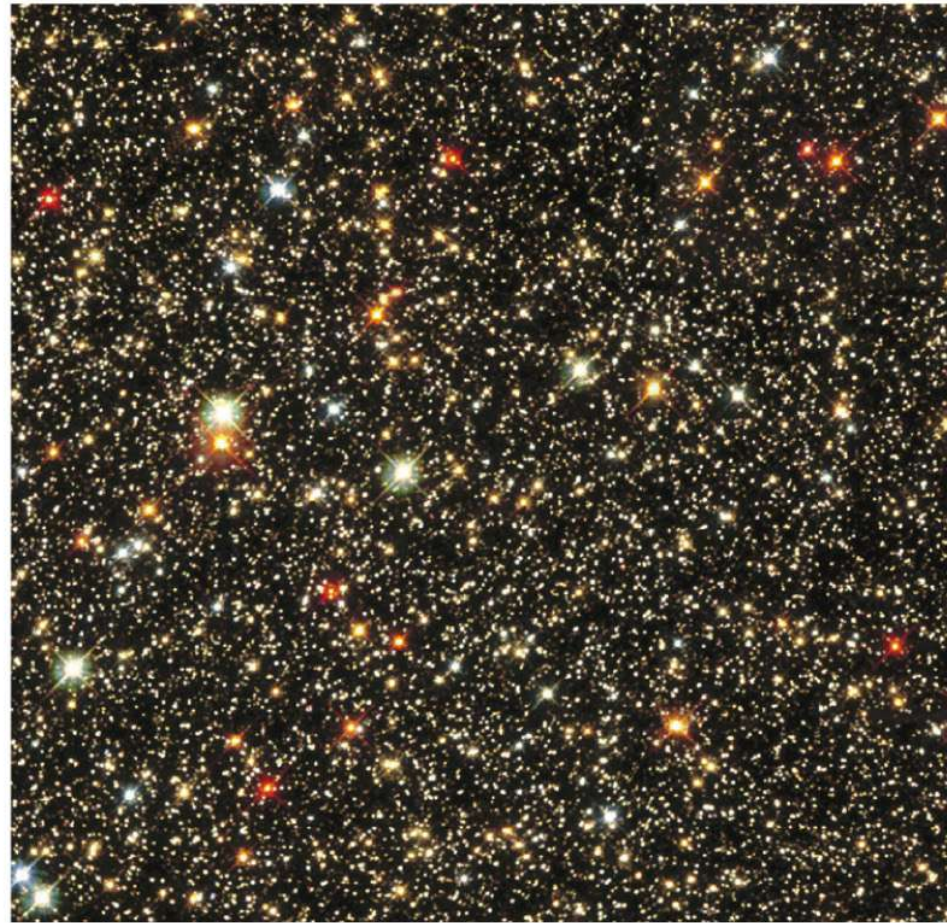
# Table 17-2
# Stellar Spectral Classes

## TABLE 17.2  Stellar Spectral Classes

| Spectral Class | Approximate Surface Temperature (K) | Noteworthy Absorption Lines | Familiar Examples |
|---|---|---|---|
| O | 30,000 | Ionized helium strong; multiply ionized heavy elements; hydrogen faint | Mintaka (O9) |
| B | 20,000 | Neutral helium moderate; singly ionized heavy elements; hydrogen moderate | Rigel (B8) |
| A | 10,000 | Neutral helium very faint; singly ionized heavy elements; hydrogen strong | Vega (A0), Sirius (A1) |
| F | 7000 | Singly ionized heavy elements; neutral metals; hydrogen moderate | Canopus (F0) |
| G | 6000 | Singly ionized heavy elements; neutral metals; hydrogen relatively faint | Sun (G2), Alpha Centauri (G2) |
| K | 4000 | Singly ionized heavy elements; neutral metals strong; hydrogen faint | Arcturus (K2), Aldebaran (K5) |
| M | 3000 | Neutral atoms strong; molecules moderate; hydrogen very faint | Betelgeuse (M2), Barnard's Star (M5) |

# Radius

a) Values for the Sun

*$R_{sun}$ = 7x10$^5$ km*

b) Range of values for other stars

0.05 Rsun - ~500 Rsun (on main sequence)

0.005 – 1000 Rsun (off main sequence, including white dwarfs and supergiants)

c) How it's measured

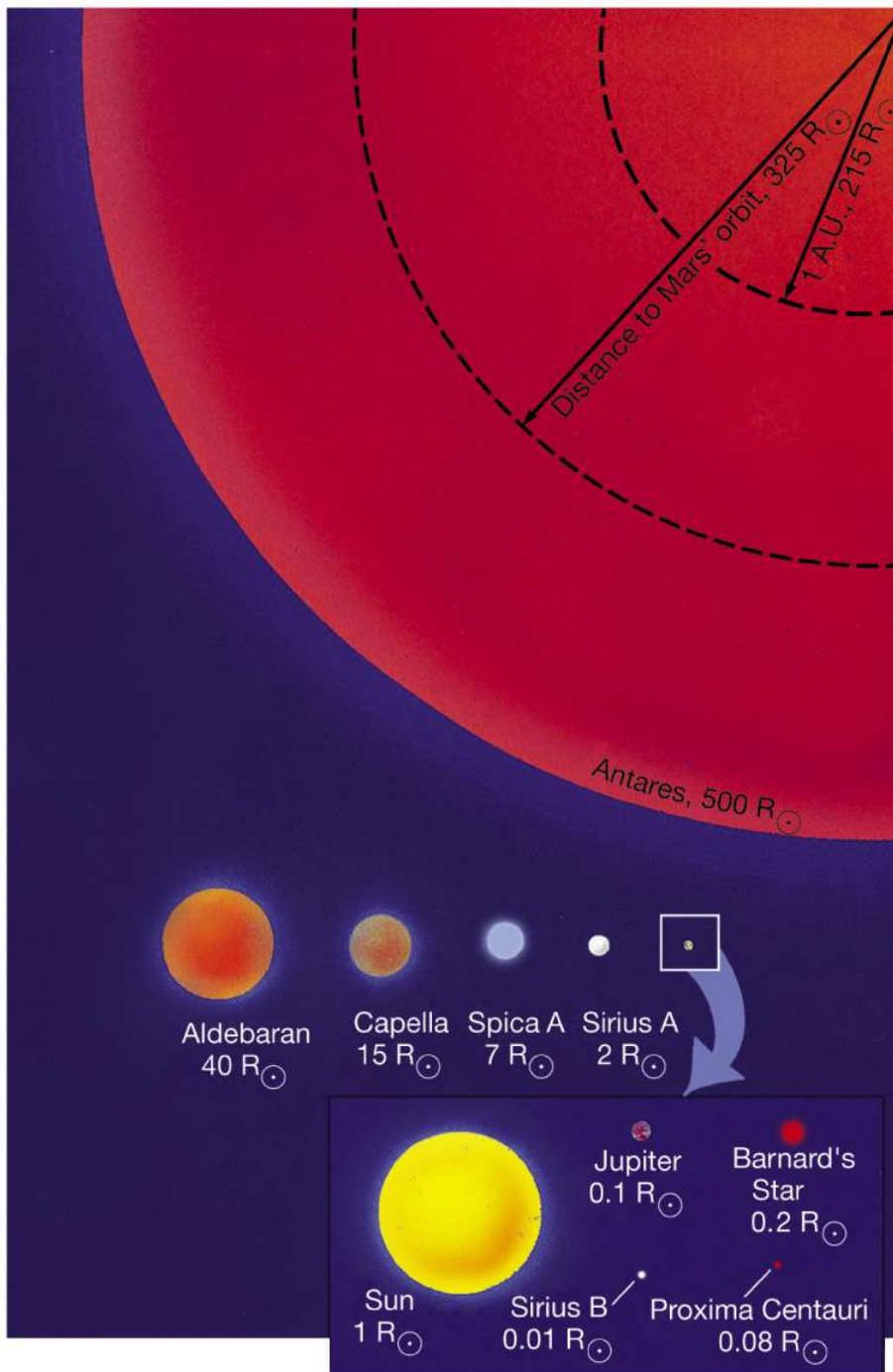Directly: by imaging and finding distance through parallaxj (or another means).

Indirectly: by finding the luminosity (which requires apparent brightness and a distance to be measured with photometry and parallax), and measuring the temperature (which requires spectroscopy).

d) Theory behind interpretation of measurement.

Direct: angle subtended (in radians) = diameter/distance
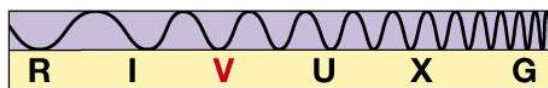
Indirect: $L = 4\pi R^2 \sigma T^4$

**Figure 17-12
Stellar Sizes**

Distance to Mars' orbit, 325 $R_\odot$

1 A.U., 215 $R_\odot$

Antares, 500 $R_\odot$

Aldebaran
40 $R_\odot$

Capella
15 $R_\odot$

Spica A
7 $R_\odot$

Sirius A
2 $R_\odot$

Jupiter
0.1 $R_\odot$

Barnard's
Star
0.2 $R_\odot$

Sun
1 $R_\odot$

Sirius B
0.01 $R_\odot$

Proxima Centauri
0.08 $R_\odot$

# Figure 17-11
# Betelgeuse



(a)

R   I   V   U   X   G
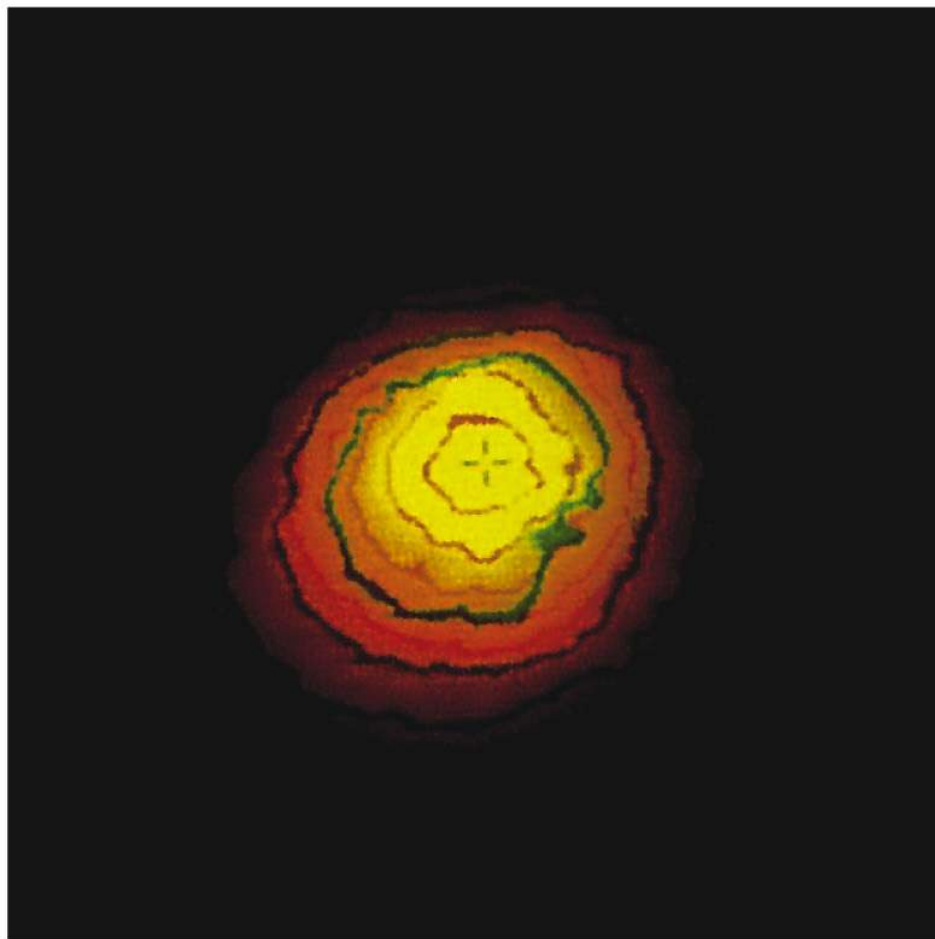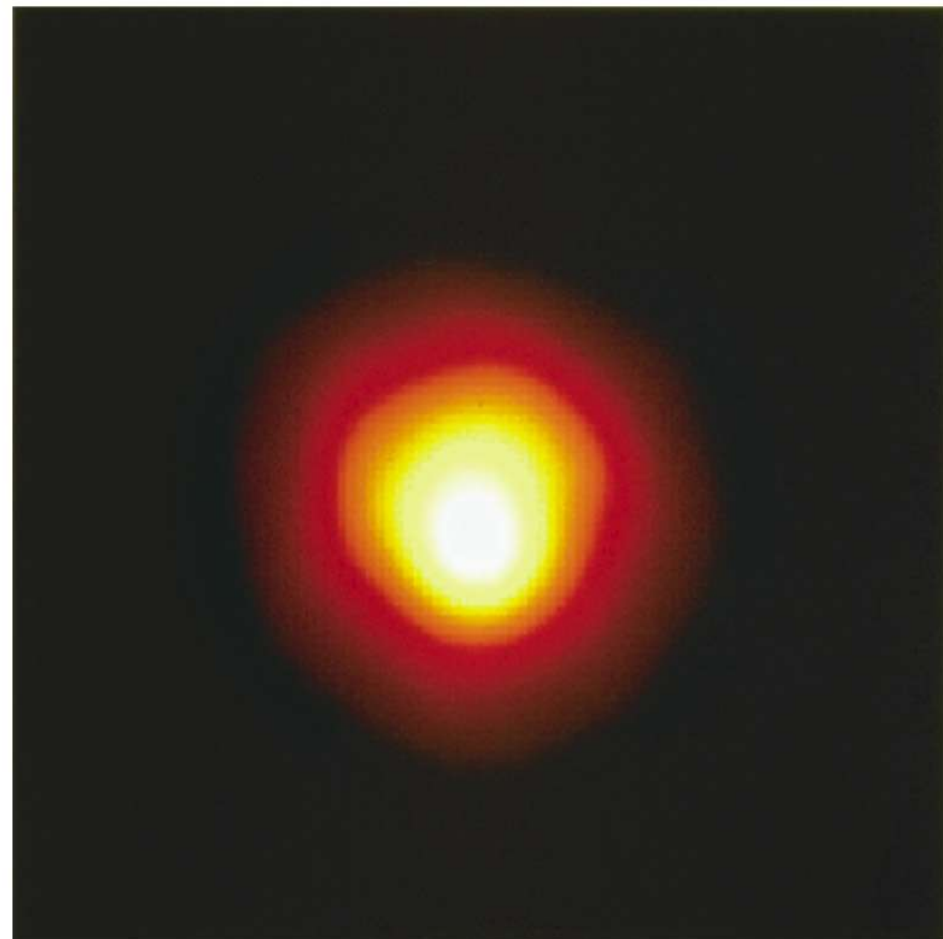
(b)

Size of Earth's orbit

R   I   V   U   X   G
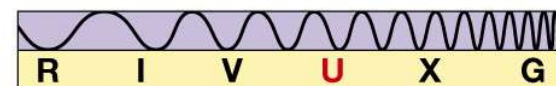
Figure 17-14
H–R Diagram of Nearby Stars
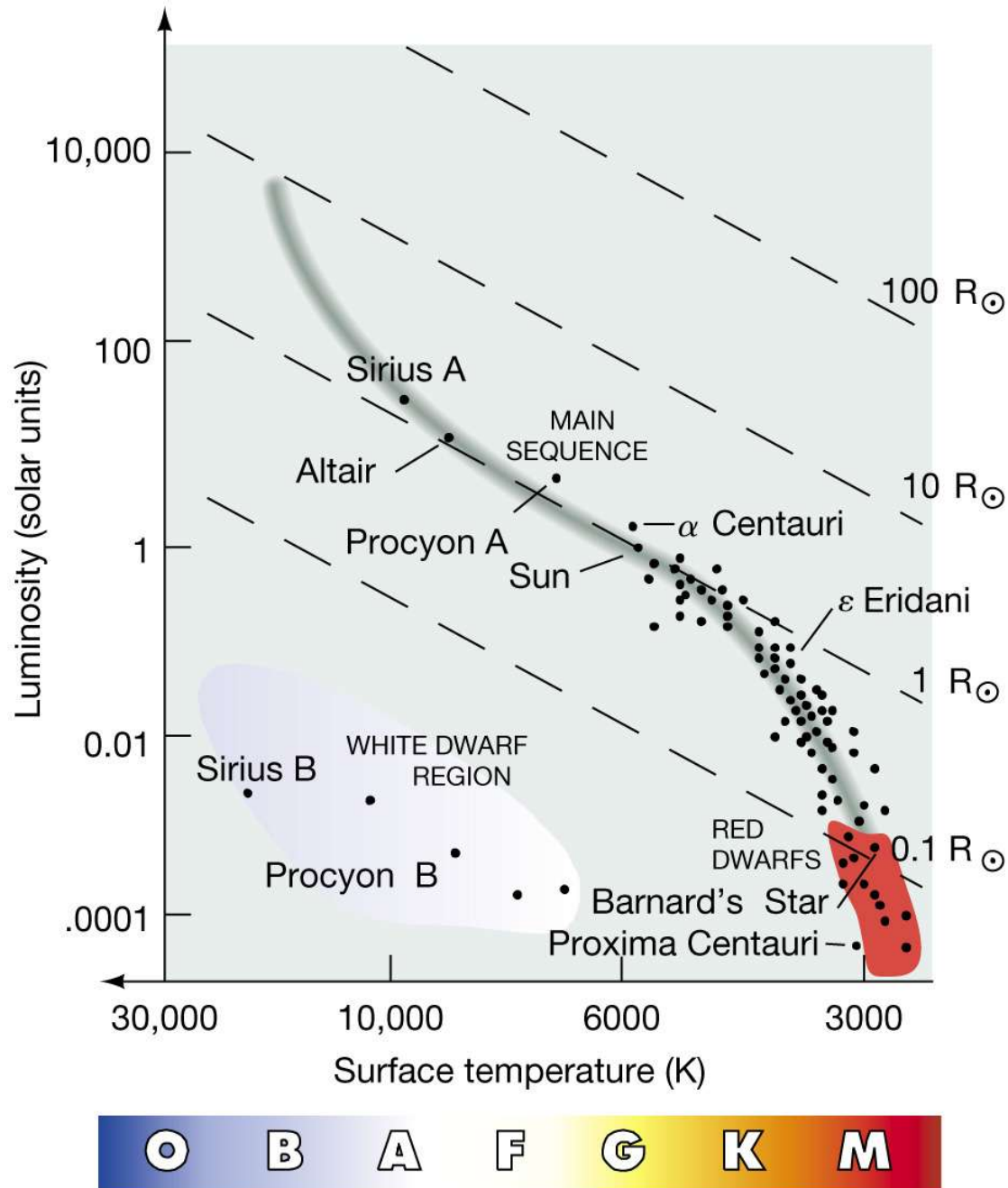
# Luminosity Class

# Table 17-3
## Stellar Luminosity Classes

| TABLE 17.3 Stellar Luminosity Classes | |
|---|---|
| **Class** | **Description** |
| Ia | Bright supergiants |
| Ib | Supergiants |
| II | Bright giants |
| III | Giants |
| IV | Subgiants |
| V | Main-sequence stars and dwarfs |
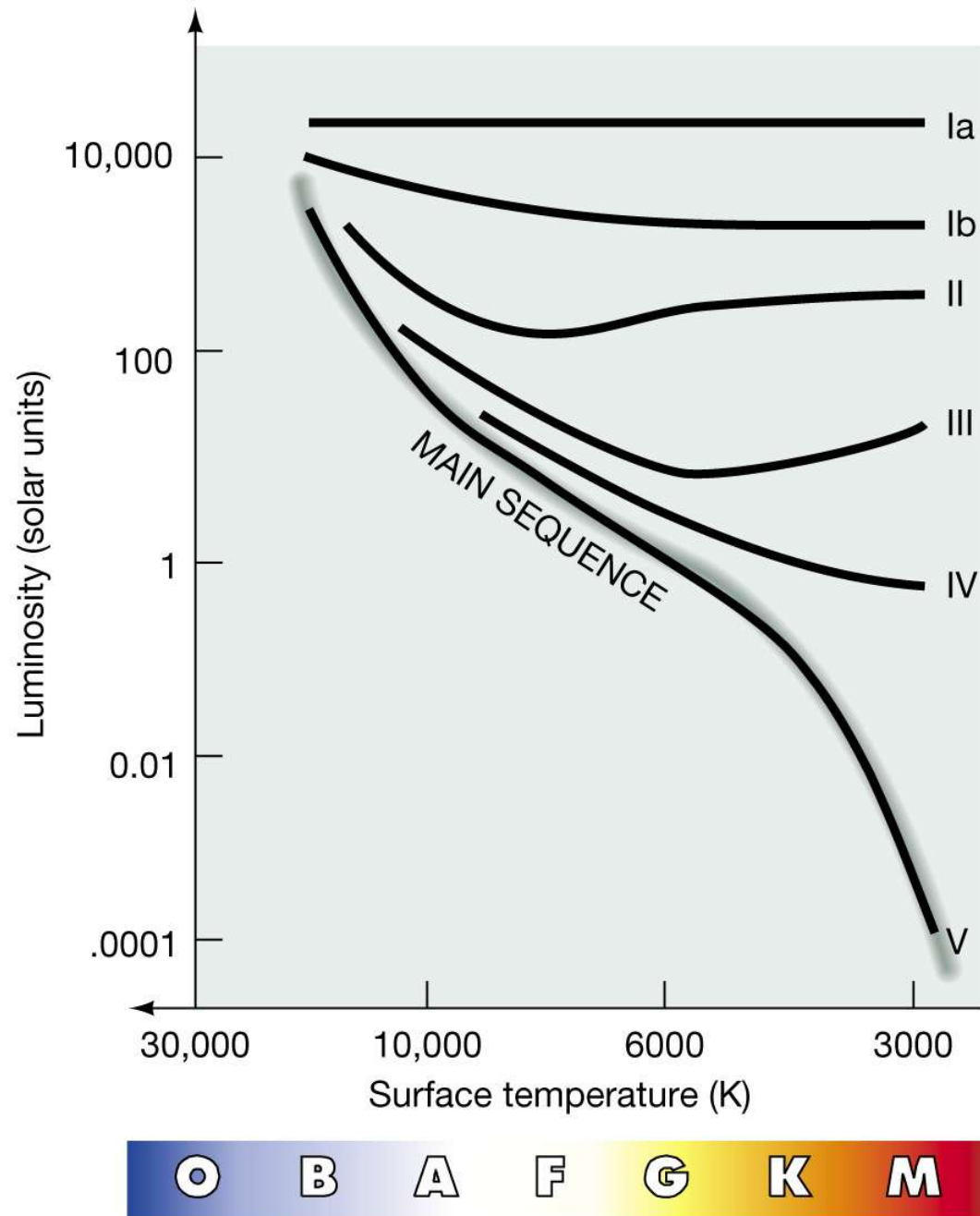
**Figure 17-18
Luminosity Classes**

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# Table 17-4
## Variation in Stellar Properties within a Spectral Class

| TABLE 17.4 Variation in Stellar Properties within a Spectral Class | | | | |
|---|---|---|---|---|
| Approximate Surface Temperature (K) | Luminosity (solar luminosities) | Radius (solar radii) | Object | Example |
| 4900 | 0.3 | 0.8 | K2V main-sequence star | ε Eridani |
| 4500 | 110 | 21 | K2III red giant | Arcturus |
| 4300 | 4000 | 140 | K2Ib red supergiant | ε Pegasi |

# Mass

a) Values for the Sun

*Msun = 2x10³⁰ kg*

$Msun = 2 \times 10^{30} \text{ kg}$

b) Range of values for other stars

0.08 Msun - ~50 Msun

c) How it's measured

Observations of binary stars.  Example: for eclipsing binaries, get the period from the light curve (photometry), get the mass ratios and the true speeds from the doppler effect (spectra).

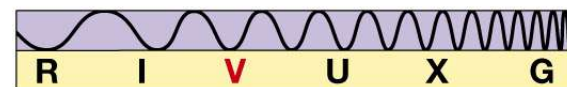Or, for visual binaries (those where two stars can be resolved), one can get the relative masses from the relative sizes of the orbits.
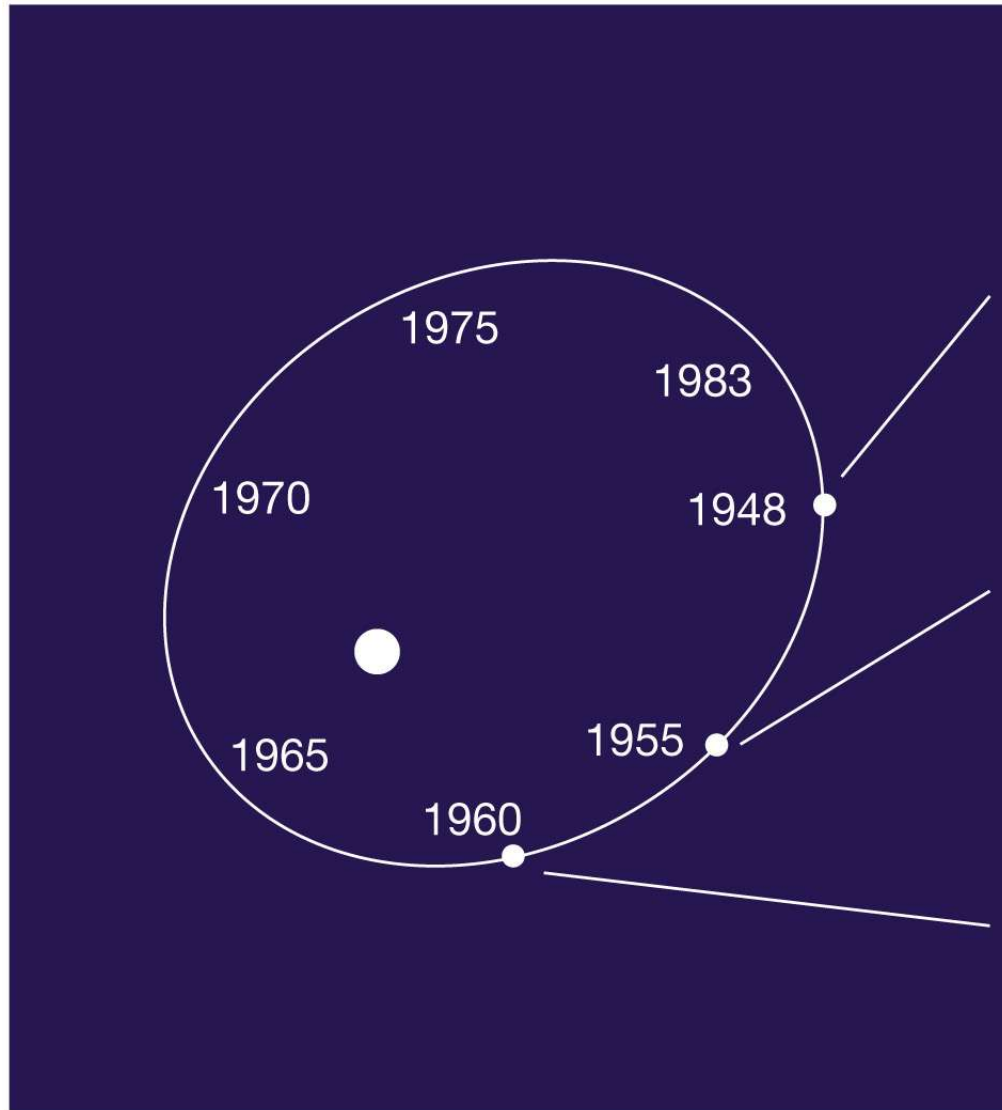
$$m_1/m_2 = r_2/r_1 \quad \text{or} \quad m_1/m_2 = v_2/v_1$$

d) Theory behind interpretation of measurement.
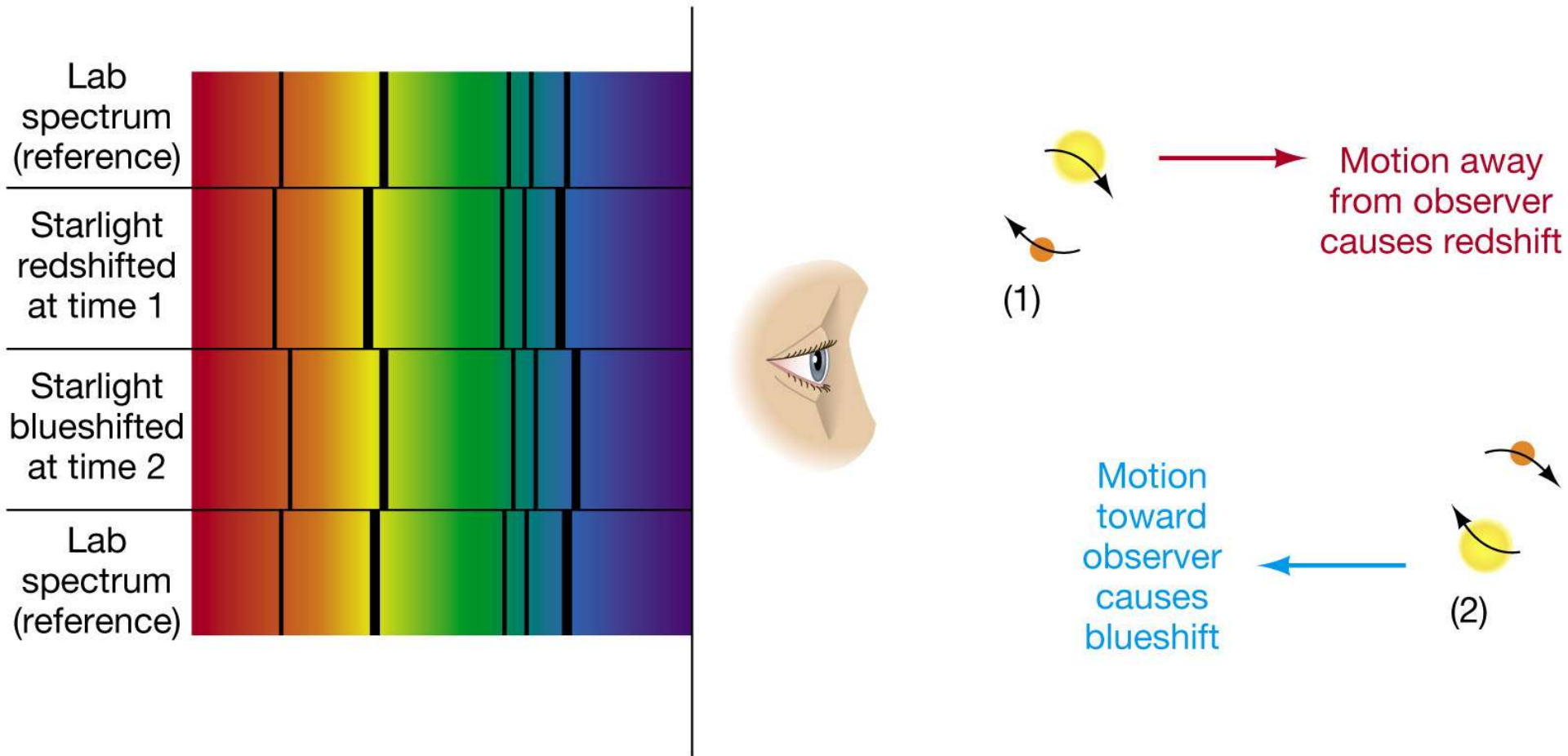
Kepler's 3rd law (with Newton's modification):

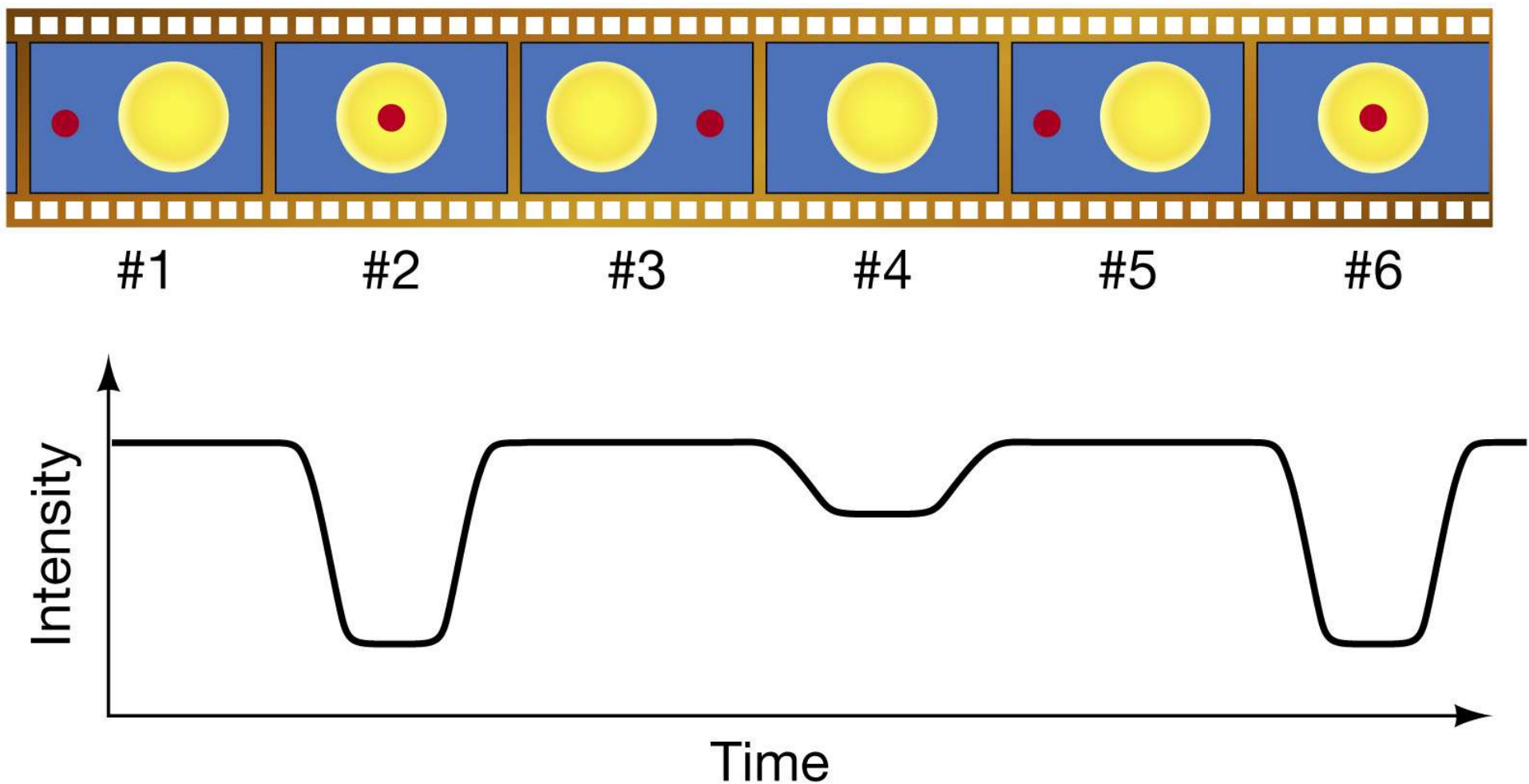$$P^2 = 4\pi\, R^3/G(m_1+m_2)$$

# Figure 17-19
## Visual Binary

# Figure 17-20
# Spectroscopic Binary



Lab spectrum (reference)

Starlight redshifted at time 1

Starlight blueshifted at time 2

Lab spectrum (reference)

Motion away from observer causes redshift

(1)

Motion toward observer causes blueshift

(2)

# Figure 17-21
# Eclipsing Binary



#1    #2    #3    #4    #5    #6

# Radial velocity / transverse velocity

a) Values for the Sun
   *Vr = 0 (on average), Vt ~ 1°/day or 1,315,000 "/year,* but this is really a reflex motion caused by the motion of the Earth around the Sun.
The motion of the Sun relative to our galaxy's center is about 200 km/s.
b) Range of values for other stars
   Speeds of stars relative to the Sun range from 0 to about 300 km/s.
c) How it's measured
   For *Vr*: Use spectrograph to get a spectrum of the star.  Measure the doppler shifting of absorption lines to get the radial velocity.
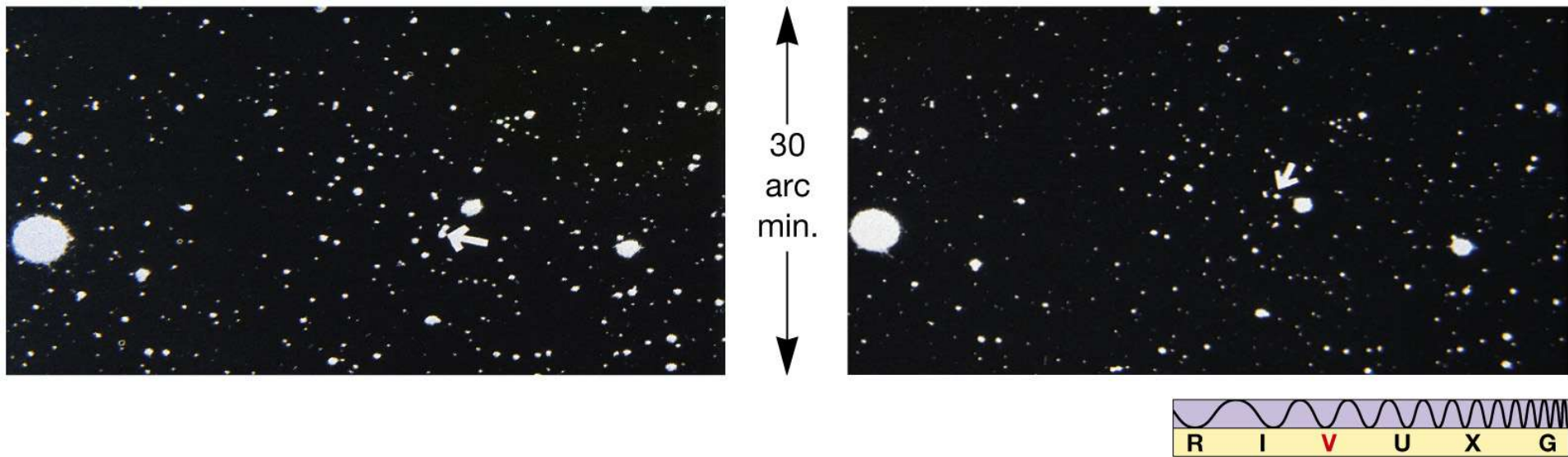   For *Vt*: Take images of the star at many different times.  Measure how many arcseconds the star moves per year relative to background stars. (One must correct for parallax, which also makes a star "move").
d) Theory behind interpretation of measurement.
    For *Vr*: the radial motion of the star causes a Doppler shift according to (observed wavelength – rest wavelength)/rest wavelength = v/c.
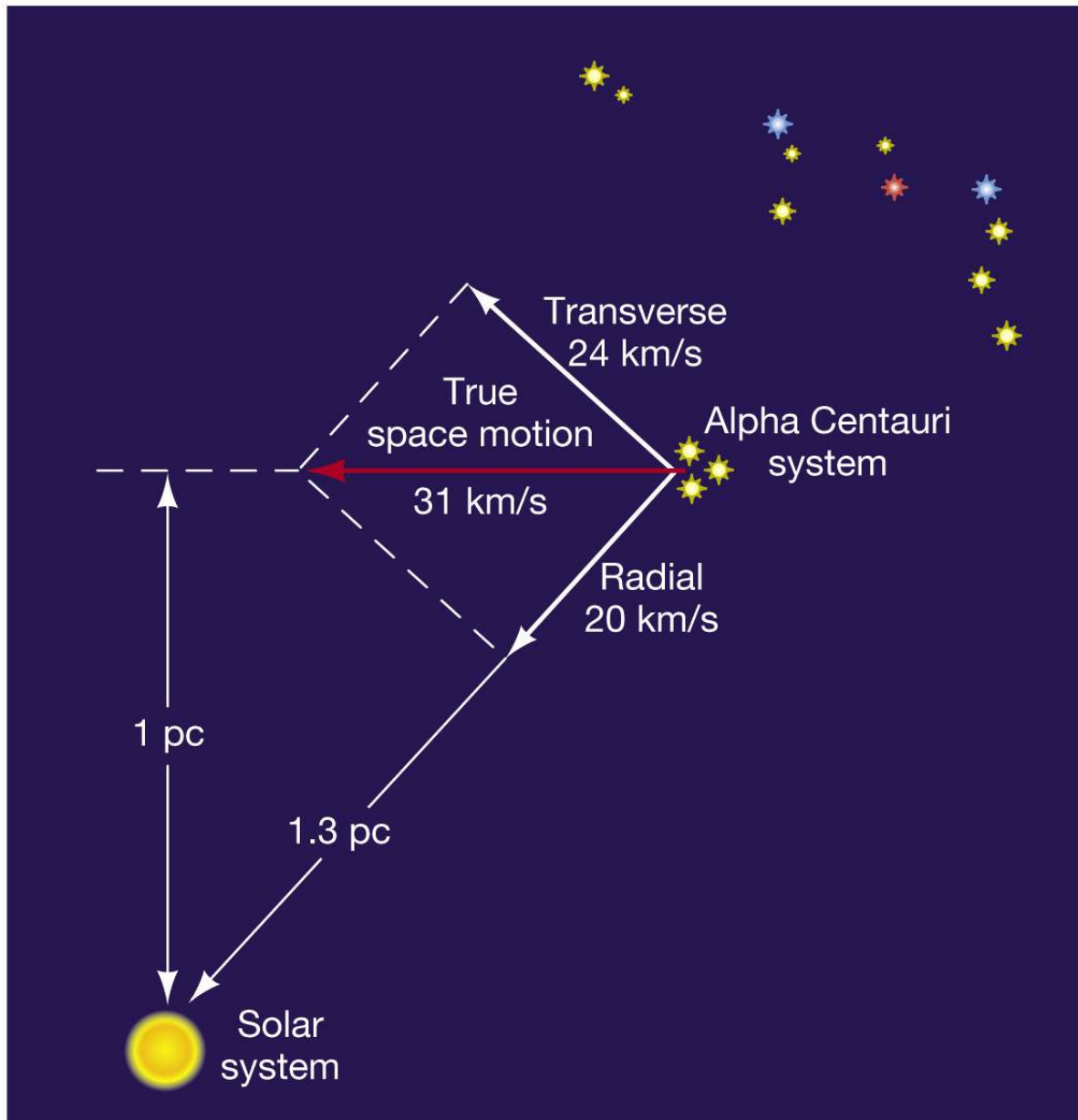    For *Vt*: simple geometry.

# Figure 17-3
# Proper Motion



30
arc
min.

R    I    V    U    X    G

# Figure 17-4
## Real Spatial Motion



Transverse
24 km/s

True
space motion

Alpha Centauri
system

31 km/s

Radial
20 km/s

1 pc

1.3 pc

Solar
system

# Composition

a) Values for the Sun
*Mostly Hydrogen (71% by mass, 91.2% by number)*
*Helium is next abundant (27.1% by mass, 8.7% by number)*
*All other elements are "metals" (1.9% by mass, 0.1% by number)*

b) Range of values for other stars
.The ratio of H/He is very similar.  But metal content differs.  Old stars have less metals and young stars have more metals.

c) How it's measured
Spectroscopy – look at absorption line strengths.

d) Theory behind interpretation of measurement.
At a given temp, the greater the line strength the greater the abundance.  Atomic physics and radiative transfer tells us what line strength to expect.

# Spectroscopic parallax

a) Values for the Sun

   NA. *(The distance to the sun is $10^{-5}$ LY*

b) Range of values for other stars

   The distance range over which spectroscopic parallax is most useful for determining distances is 1000 LY – 40,000 LY.
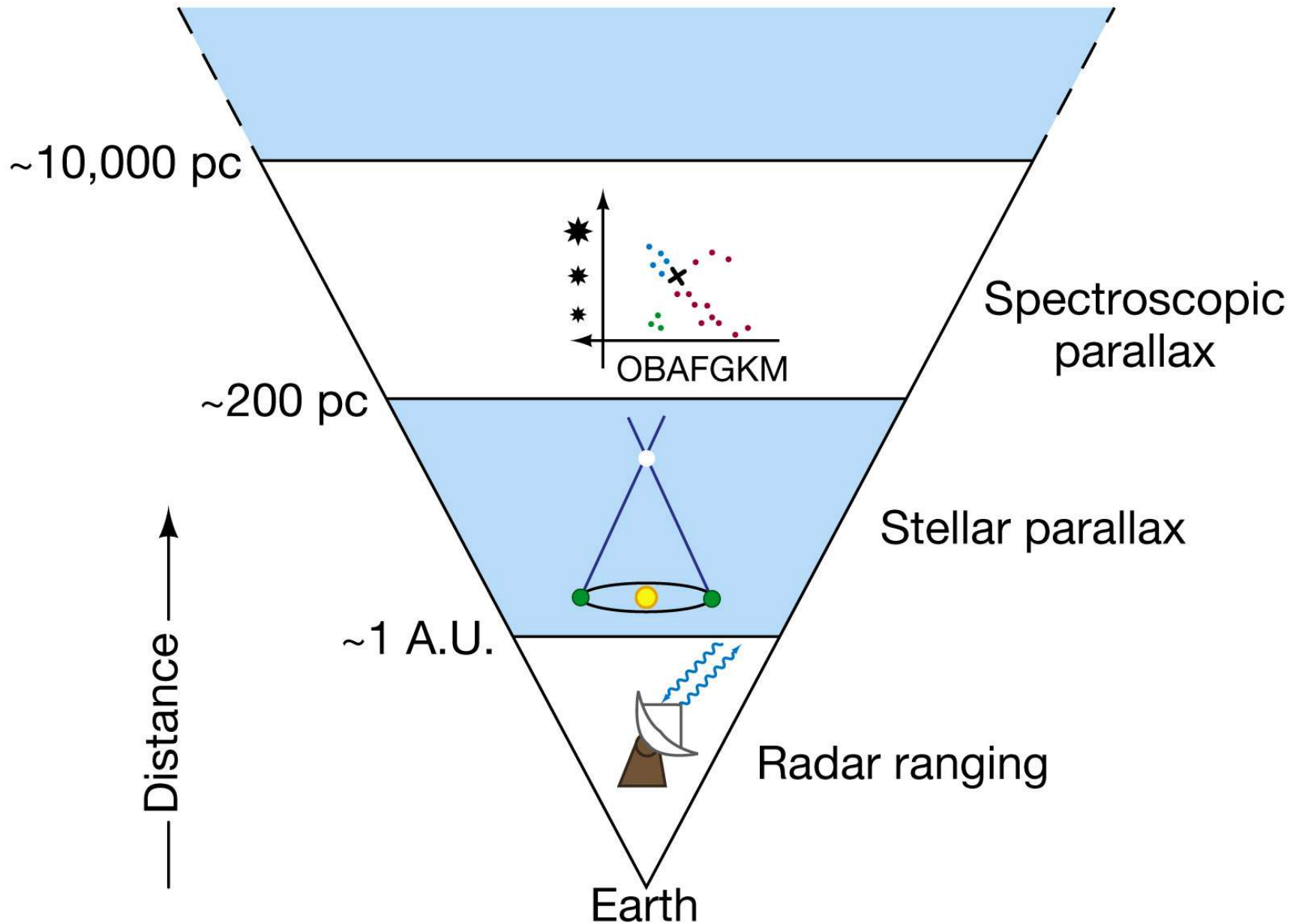
c) How it's measured

   For single stars: Spectroscopy is used to identify the spectral type of a star, including its luminosity class.  From this, one estimates the stars luminosity (L or $M$).  The difference between the apparent brightness, $m$, and $M$ gives a distance.

   For a cluster of stars: two-color photometry can be done on a cluster of stars to obtain color index (B-V or B/V) and apparent brightness, $m$, for each star.  A plot of $m$ vs B-V will exhibit a Main Sequence just like a real H-R diagram (a plot of $M$ vs B-V).  The vertical offset of the cluster's main sequence from the main sequence on $M$ vs B-V gives us ($m$-$M$) and thus a distance for the entire cluster.  (This is called main-sequence fitting.)

d) Theory behind interpretation of measurement.

   m-M = 5 log (D/10pc).  Where D is the distance in pc.

# Figure 17-17
## Stellar Distances

~10,000 pc

OBAFGKM

Spectroscopic parallax

~200 pc

Stellar parallax

~1 A.U.

Radar ranging

Distance

Earth

# H-R Diagram

a) Values for the Sun

The Sun's position on the H-R Diagram is Spectral Type = G2, L=1Lsun.
The Spectral Type can be replaced by surface temperature (5800 K), or color index
(B/V=0.55, B-V=0.65 ).
The Luminosity, L, can be replaced by absolute magnitude, M=+4.83.

b) Range of values for other stars

(See an H-R diagram.) The surface temperatures range from 3000-30000 K, and
the luminosities range from about 0.0001 – 100,000 Lsun.

c) How it's measured

Spectroscopy is used to identify the spectral type, or surface temp. of a star.
Two-color photometry can give the color index of the star. The luminosity can be found,
for example, by getting a distance and a flux (or apparent magnitude).
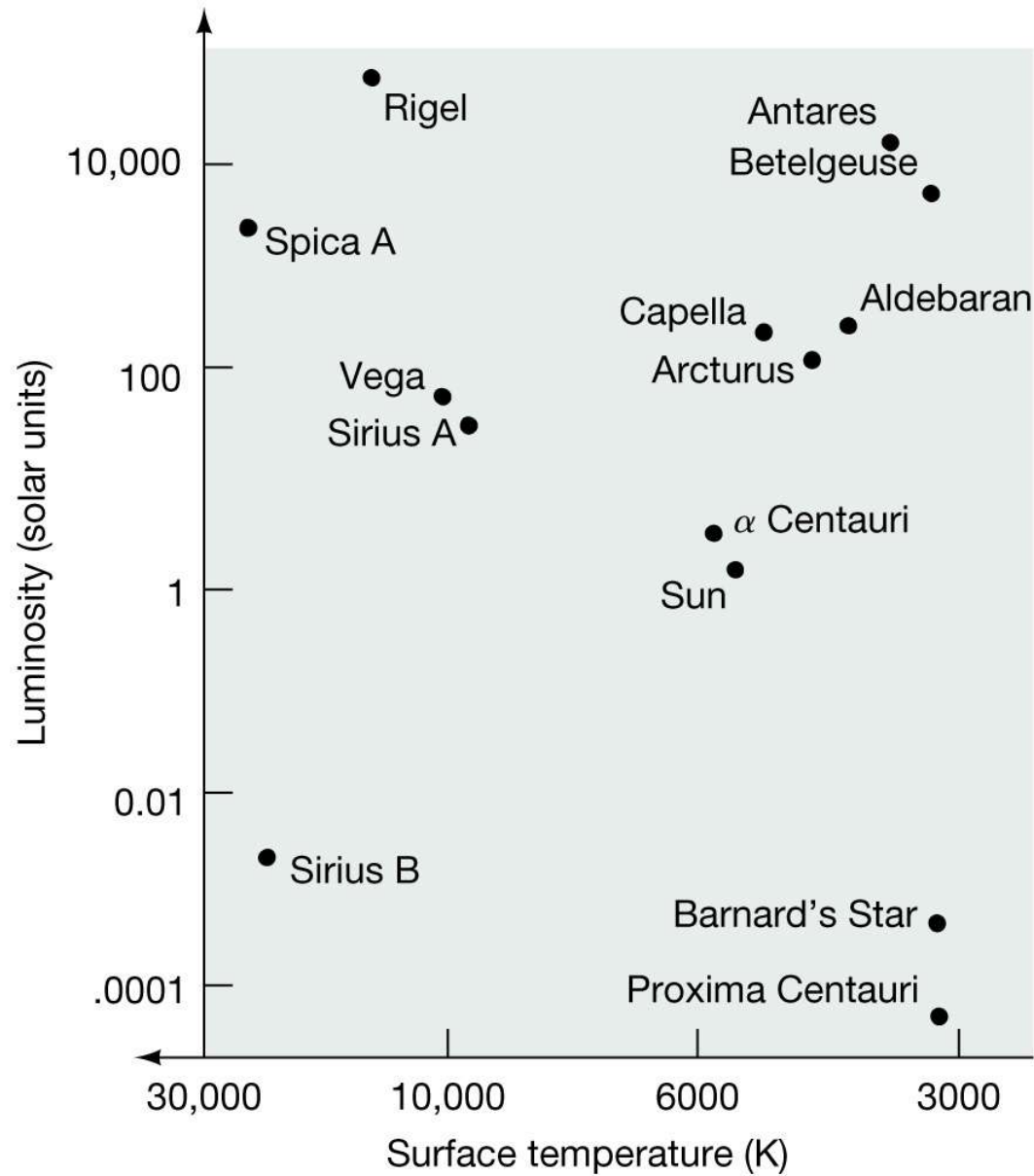
d) Theory behind interpretation of measurement.

The placement of a star on the H-R diagram tells us about the stars mass and its stage
in evolution.  Stars on the Main Sequence (MS) are fusing H to He in their core, and this
is the longest stage in their evolution.  The MS is really the "mass-luminosity" relation in
disguise, with the top left of the MS being high mass stars and the bottom right being low
mass stars.  The mass-luminosity relationship is $L \sim M^4$
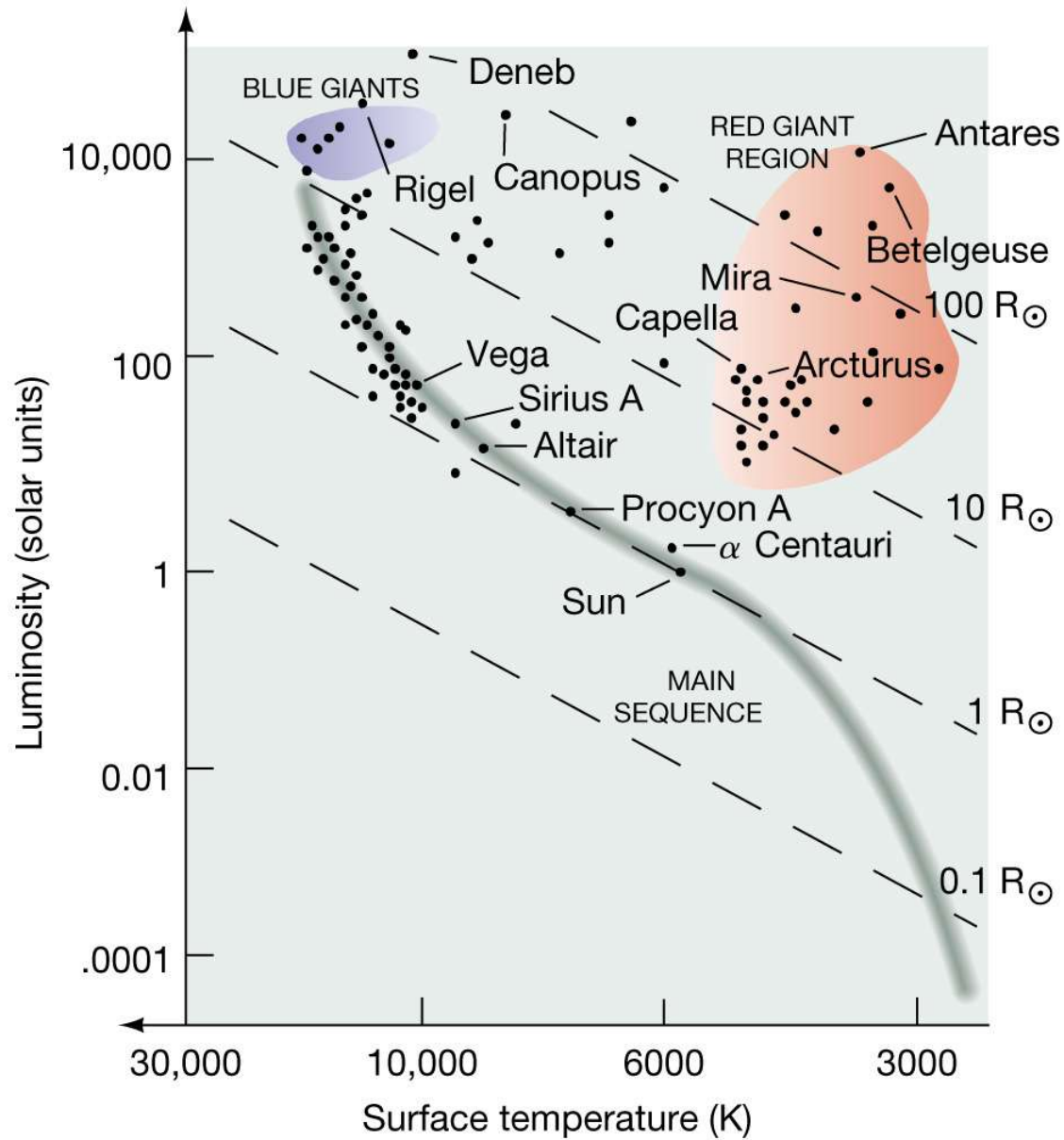
**Figure 17-15
H–R Diagram of Bright Stars**

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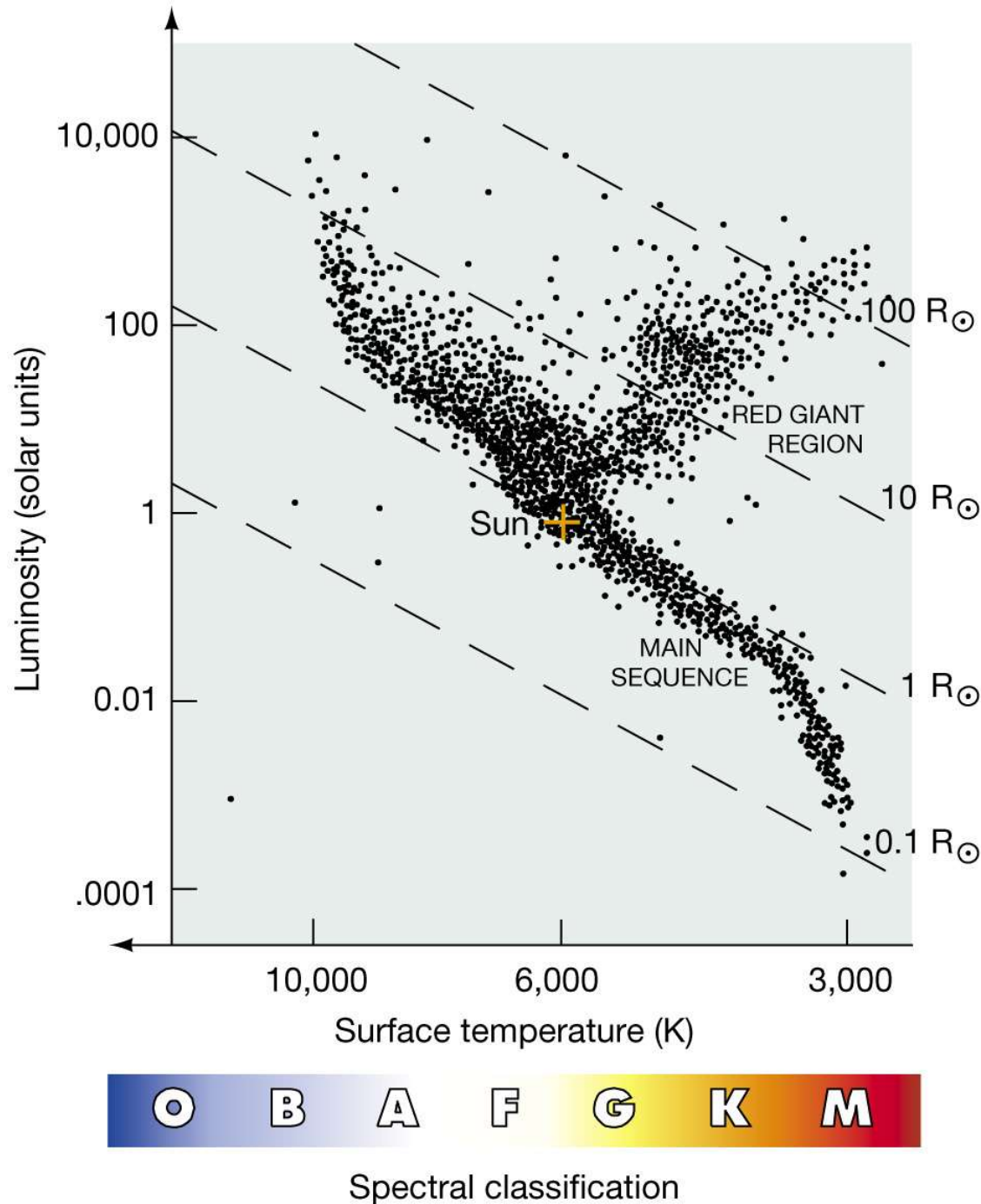
**Figure 17-13**
**H–R Diagram of Prominent Stars**

Spectral classification

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**Figure 17-16**
*Hipparcos* H–R Diagram

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**Figure 17-22
Stellar Masses**

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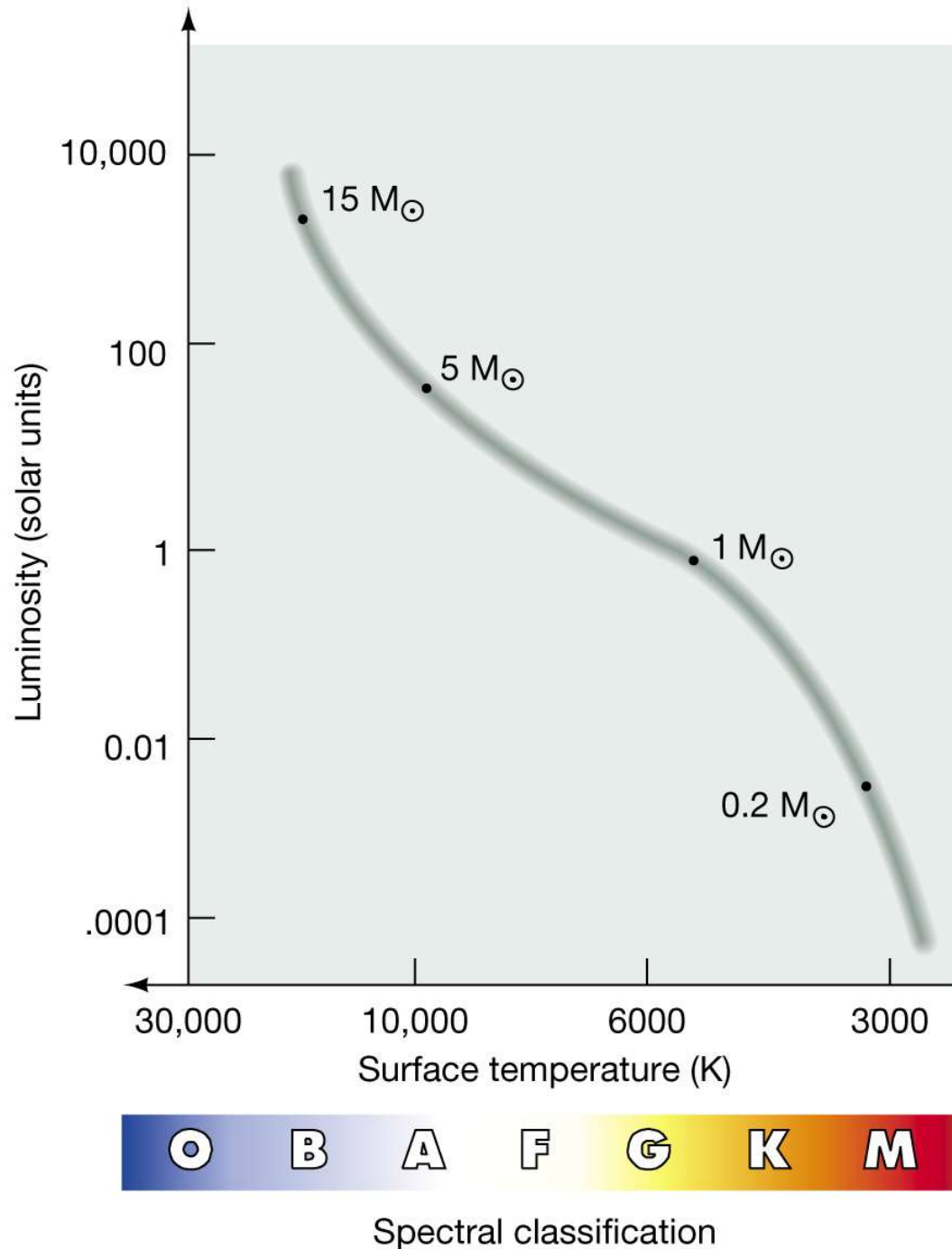
# Figure 17-23
# Stellar Mass Distribution



Blue giants

>20 M$_\odot$
0.06%

4-8 M$_\odot$
0.8%
giants

8-20 M$_\odot$
0.3%

2-4 M$_\odot$
3%

1-2 M$_\odot$
8%

<0.25 M$_\odot$
41%
Red dwarfs

0.5-1 M$_\odot$
19%

0.25-0.5 M$_\odot$
28%
Dwarfs
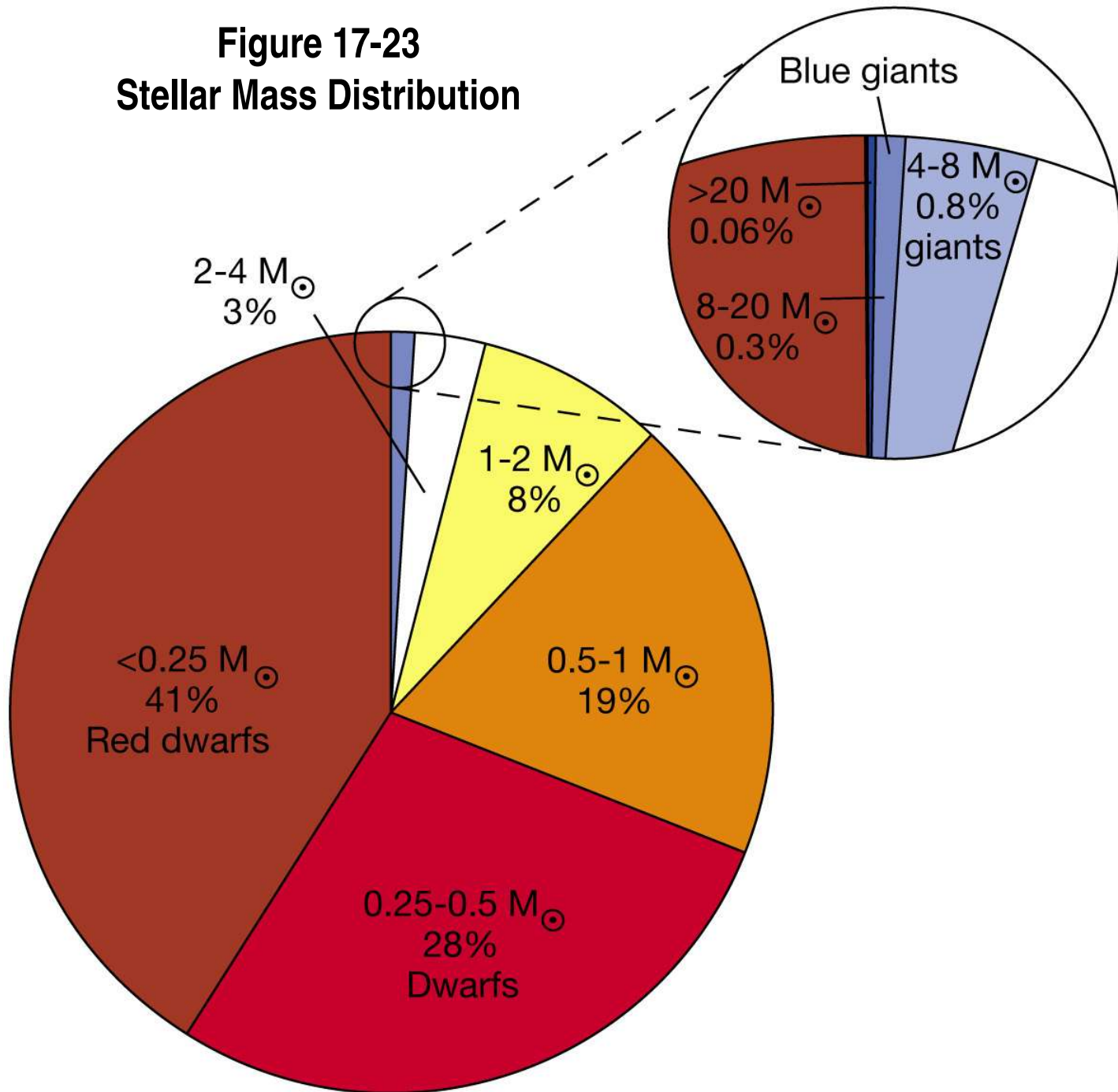
# Figure 17-24
# Stellar Radii and Luminosities



(a)

(b)