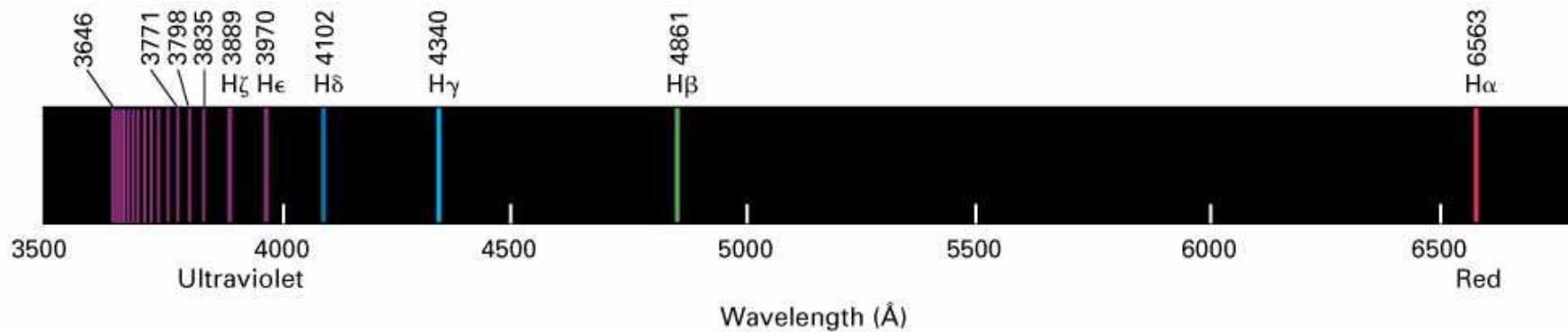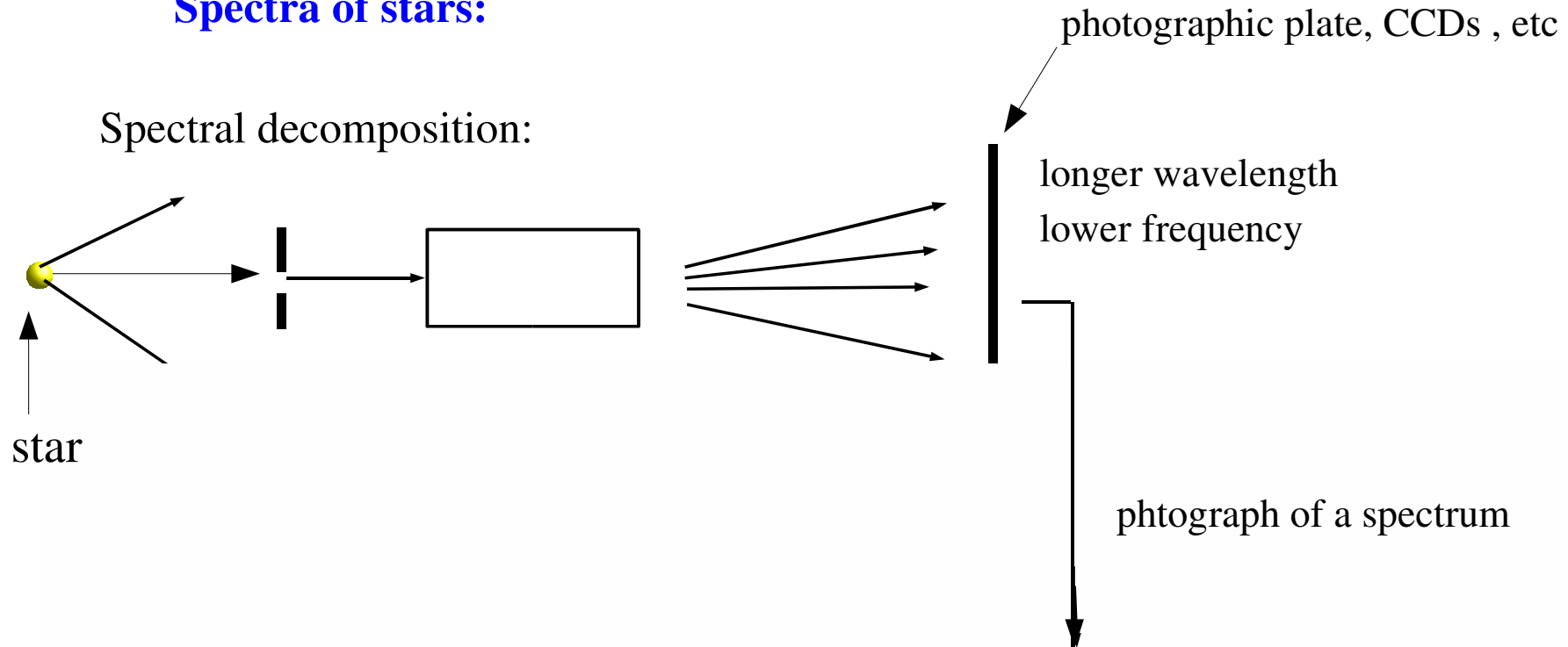# Classification of Stars

Chapter 11

Topics :

1. Colors, Temperature and Spectra of Stars.

2. Stellar distances: Astrometry

3. Stellar Luminosities or Power emitted

4. Herzsprung-Russell (Luminosity versus Temperature) distribution

5. Detecting stellar motions: Proper motions and radial velocities

6. Stellar binaries: How do we weigh stars.

Color , spectra and temperature of stars -1

Spectra of stars:

photographic plate, CCDs , etc

Spectral decomposition:

longer wavelength
lower frequency

star

phtograph of a spectrum

3646	3771 3798 3835 3889 3970	4102	4340	4861	6563
	Hζ Hε	Hδ	Hγ	Hβ	Hα

3500   4000   4500   5000   5500   6000   6500
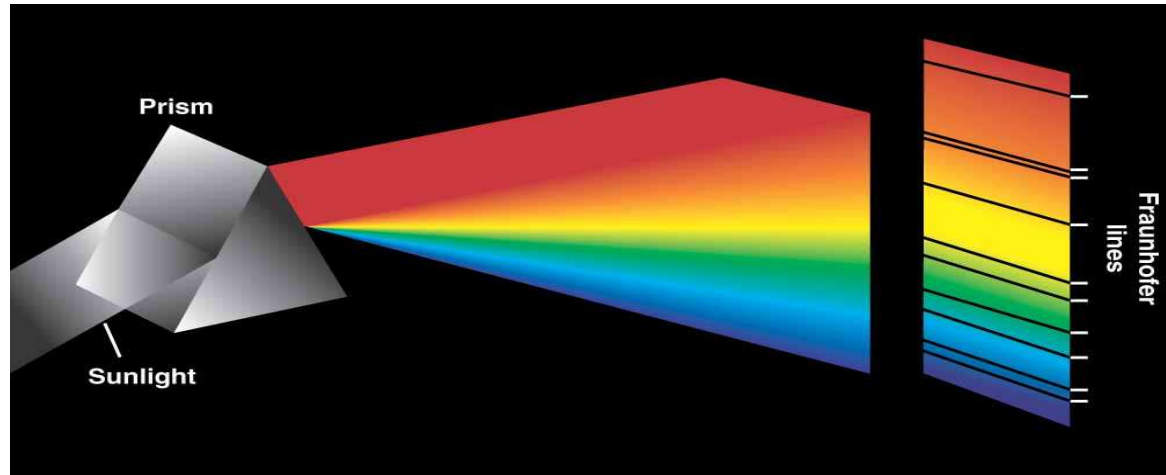
Ultraviolet   Red

Wavelength (Å)

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If the star emits only Hydrogen emission lines.

Color , spectra and temperature of stars -2
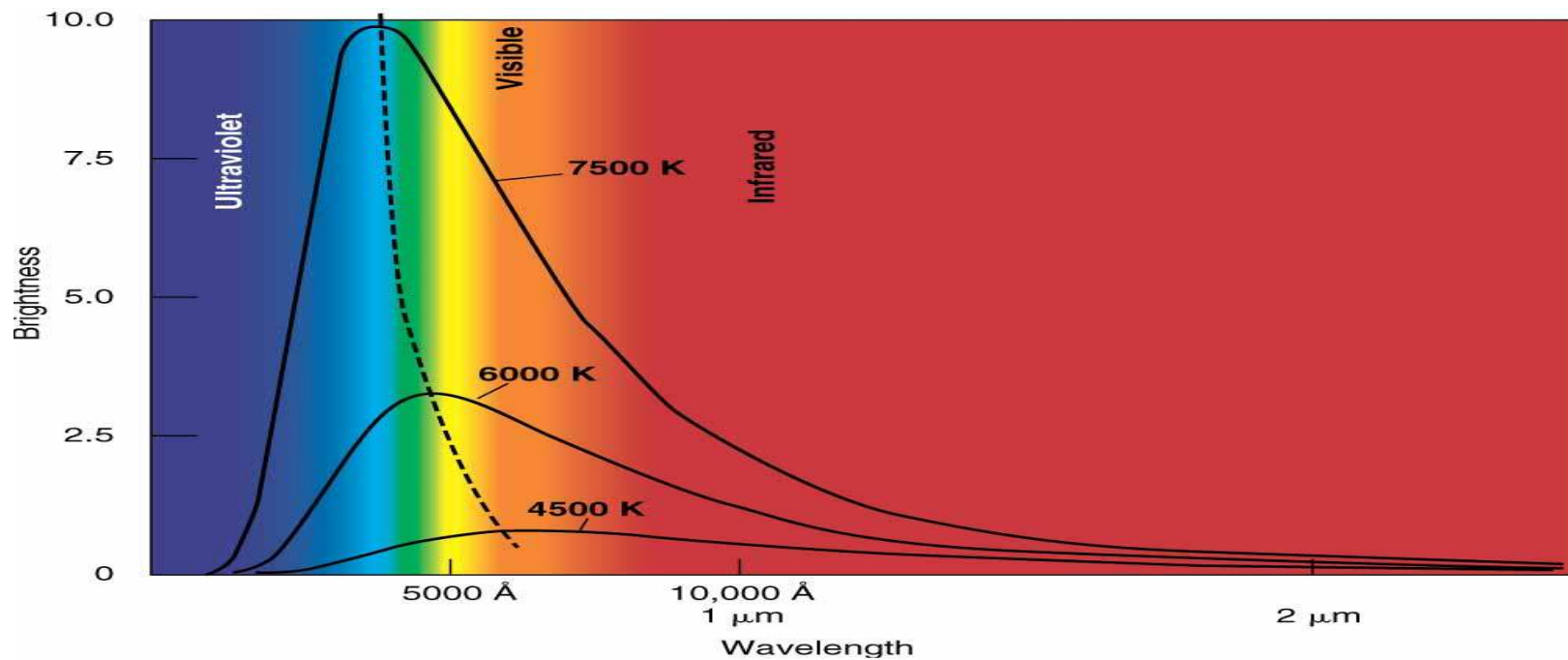
Spectra of stars continued:

A prism spectrograph

Ignoring the line spectra, brightness is measured as a function of wavelength
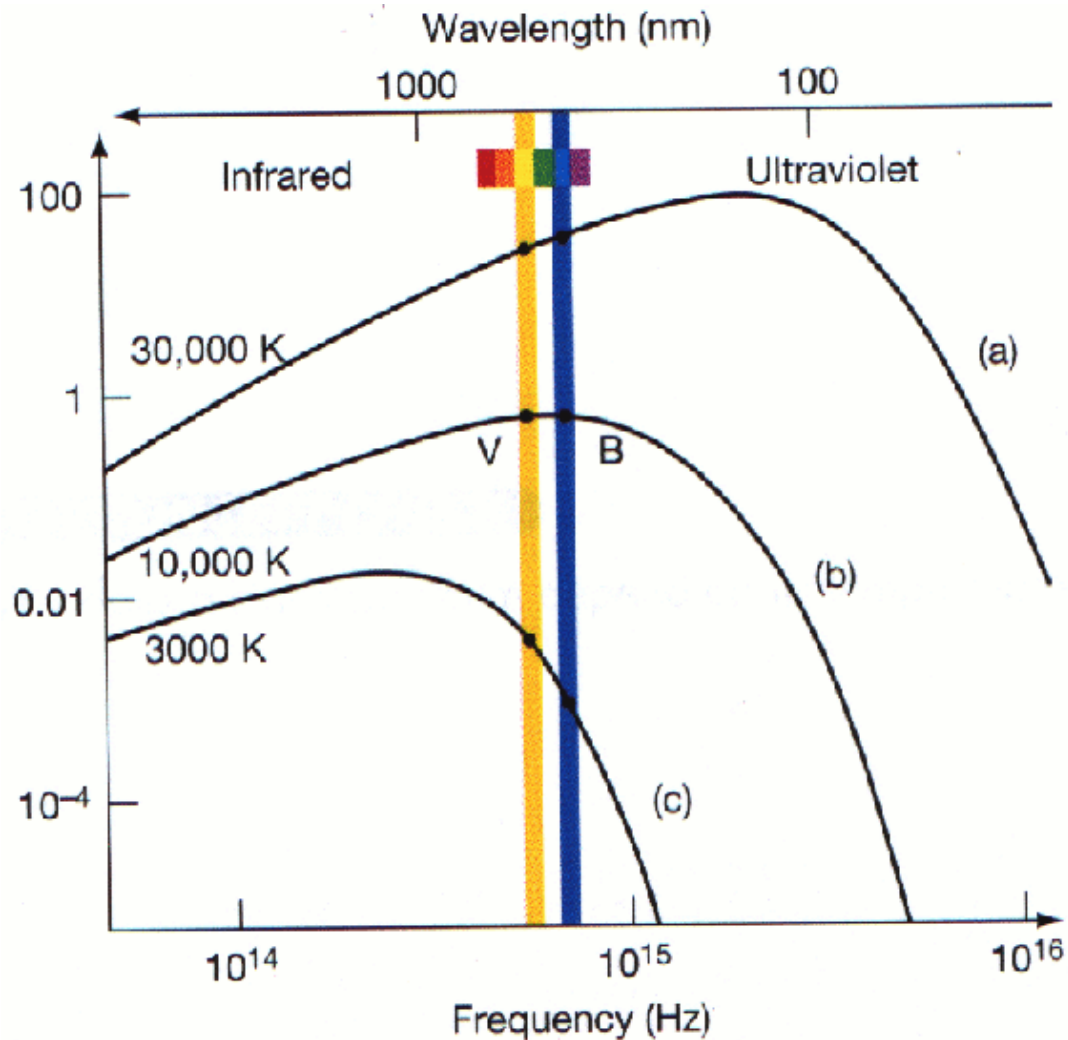

higher frequencies ⟵ lower frequencies

Color , spectra and temperature of stars -3

Spectra of stars with different surface temperatures and color index B-V
as measure of temperature.

Color , spectra and temperature of stars -4

1.Brightness versus wavelength (or frequency) from stars is ~ black-body spectrum.
Black body spectrum depends only on the temperature of the emitting star's surface.

2. Locate the position of the maximum and you can calculate the temperature:

$$\lambda_{max} \times T_{surface} = 0.29 \, cm \, K$$

Consider the sun:

For the sun $\lambda_{max} = 5000 \, Angstroms = 5 \times 10^{-5} \, cm$

the surface temp is $T = 5800 \, K$

Consider a star emitting in UV: $\lambda_{max} = 2000 \, Angstroms$

Its surface temperature is : $14,500 \, K$

Hotter stars are blue and red stars are relatively cool on the surface !
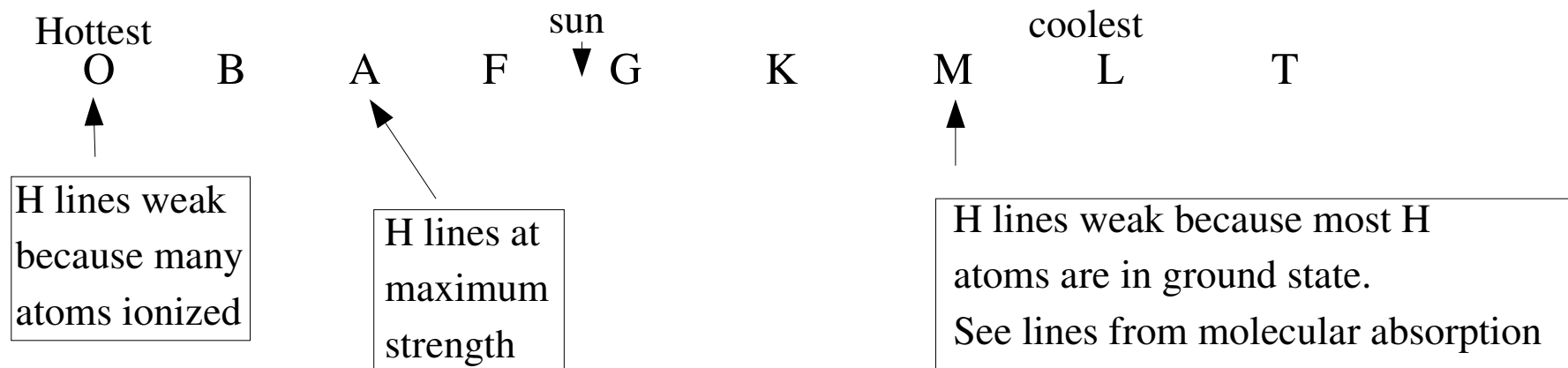
3. or you can compare the spectra to computer models of spectra of stars with
different temperature and develop an accurate color-temperature relation.

Color , spectra and temperature of stars -5

Star classification:

Stellar temperature is by far the most important property which determine the structure of the observed spectrum. Detailed calculations can be compared with observed spectra to assign surface temperature to stars.
Stars are classified this way and assigned letters:

Hottest   sun   coolest

O   B   A   F   G   K   M   L   T

H lines weak because many atoms ionized

H lines at maximum strength

H lines weak because most H atoms are in ground state.
See lines from molecular absorption

going from O which has the highest temperature ~ 50,000 K
to T which has the lowest temperature , M ~ 3000 K.

Color , spectra and temperature of stars -6

Temperature and Spectral features
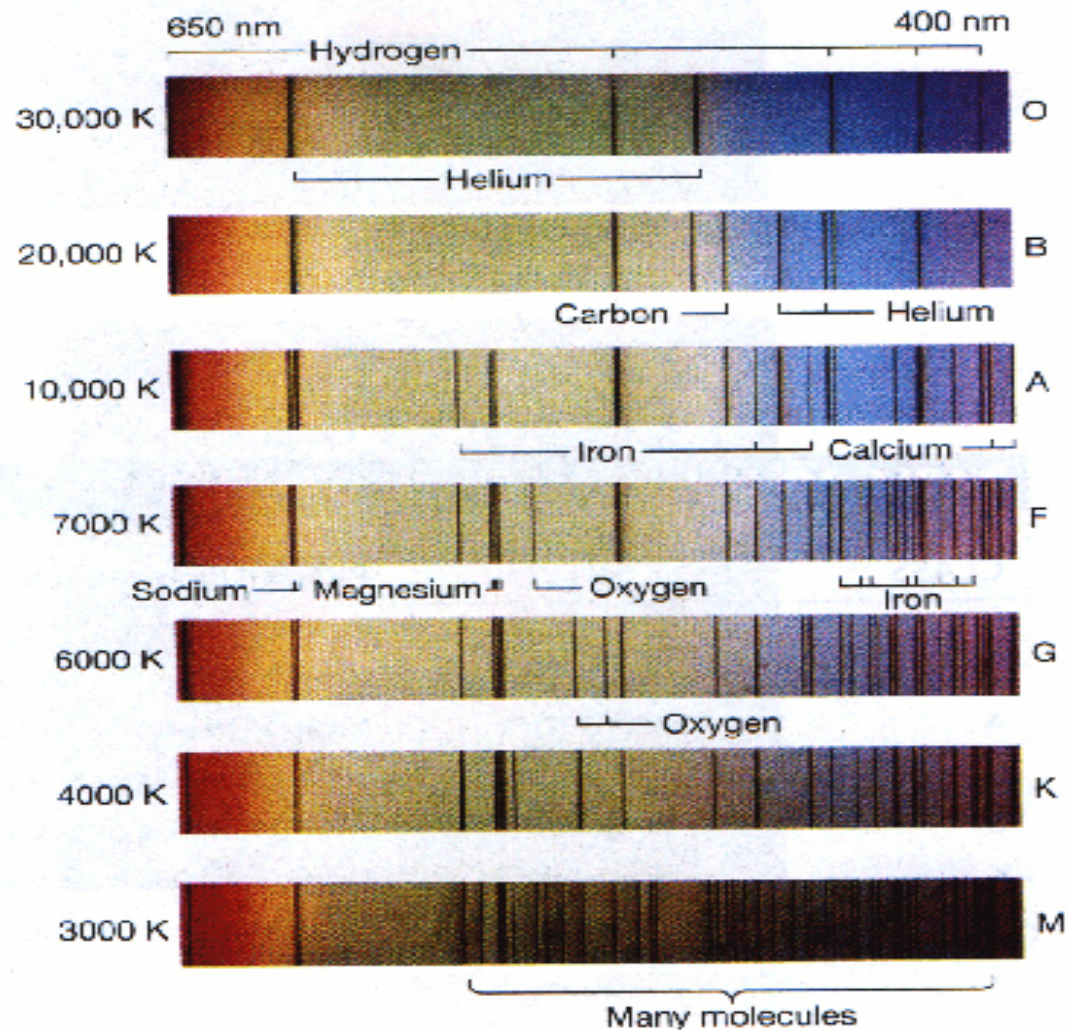
Astrometry -1

Stellar Distances:

Method of triangulation:

For nearby stars, their position on the celestial sphere of very distant stars, shifts when viewed from the earth from different positions in earth's orbit. This can be quantified in terms of parallax. Knowing the radius of earth's orbit their distance can be calculated.

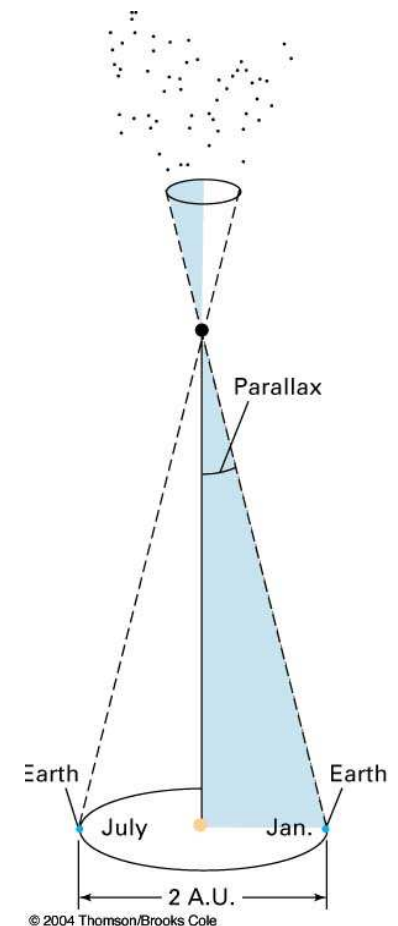Calling the parallax angle p and noting that earth's radius is 1 AU

Distance to the star d is: $d = \dfrac{1\,AU}{p}$

For example if $p = 0.5\,sec\,of\,arc$ and noting that 1 sec of arc $= \dfrac{1\,deg}{3600}$

and 1 deg $= \dfrac{1}{57.3}$ radians 0.5 arc sec $= 2.42 \times 10^{-6}$ radians

$$d = \frac{1.46 \times 10^{11}\,m}{2.42 \times 10^{-6}} = 6 \times 10^{13}\,m$$

or in light years (1 ly $= 9 \times 10^{15}$ m) it is 6.75 ly

Parallax

Earth

Earth

July   Jan.

2 A.U.

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Astrometry -2

The Hipparcos satellite instrument launched in 1989 has measured some 118,000 stars out to about 300 ly !

Our galaxy has a much larger size than 300 ly ! Some 100,000 lyrs.

So different techniques have to be developed to get distances to stars that are further away. One method is to calculate luminosity distance. This is called the method of spectroscopic parallax.

Spectral Type and Distance :

Direct triangulation (discussed next) extends up to ~ 360 ly. Spectral type and brightness used to estimate further distances. Called Spectroscopic Parallax

1. Take a spectrum of a star

2. Find the closest match in spectral type amongst nearby stars which have been triangulated and their distance known.

3. Assume that the nearby and distant objects are the same sort of star, specifically they have the same luminosity.

4. Now compare the apparent brightness and luminosity and apply the inverse square law and you have the distance.

Now we have a set of stars for which we know:

1. Apparent magnitude of brightness
2. Temperature and intrinsic luminosity
3. Distance

To compare these stars and look for some order, we calculate the **absolute magnitude** or brightness at a standard distance and plot the absolute magnitude versus surface temperature. We get the Herzsprung Russell diagram.

A star which appears faint, but whose intrinsic luminosity we know from analysis of its spectra, should be much brighter at the standard distance if it is far away.

Next Step:

We use the sample of stars whose distances are known and whose apparent brightnesses have been measured.

We want to find out if there is some connection between their surface temperature and their brightness.

To do this we find out the brightness of all these stars if they had all been placed at some fixed distance. We can do this in two different ways:

1. **Calculate using inverse square law their absolute brightness at this fixed distance – knowing their actual distance from triangulation or**

2. **Look at the apparent brightness versus color(surface temp) for a set of stars which belong to a cluster of stars – which can be safely be assumed to be at the same distance.**

Figure 10.13 H–R Diagram of Nearby Stars Most stars have properties within the ... region, ... for stars lying within about 5 pc of the Sun. Each dot represents a star whose luminosity and temperature have been measured. ... the H–R diagram known as the main sequence. The ... Each dotted diagonal line corresponds to a constant stellar radius, so that stellar size can be indicated on the same diagram ... depends on stellar luminosity and temperature. (Recall that the symbol "⊙" means "solar," as indicated in the analogy, most people fall along a "main sequence," as well.

... very luminous stars sample a much greater volume of space than those ... are scattered through ... Figure 10.14 sample is heavily biased toward the ... and the Figure 10.14 ... luminous objects. In fact, of the 20 brightest stars in the sky, only six lie within 10 pc of us. The rest are visible, despite their great distances, because of their high luminosities.
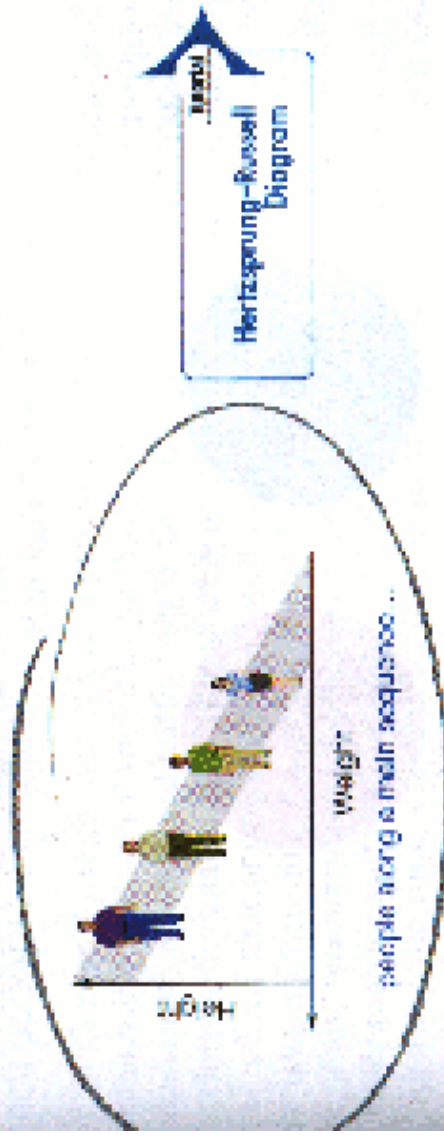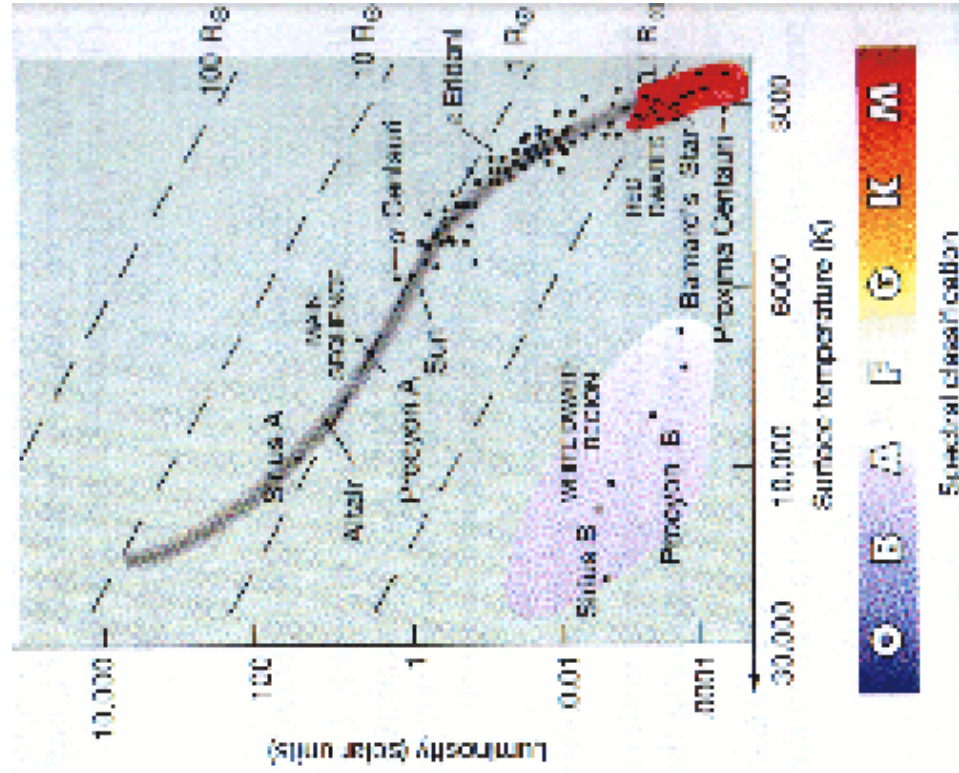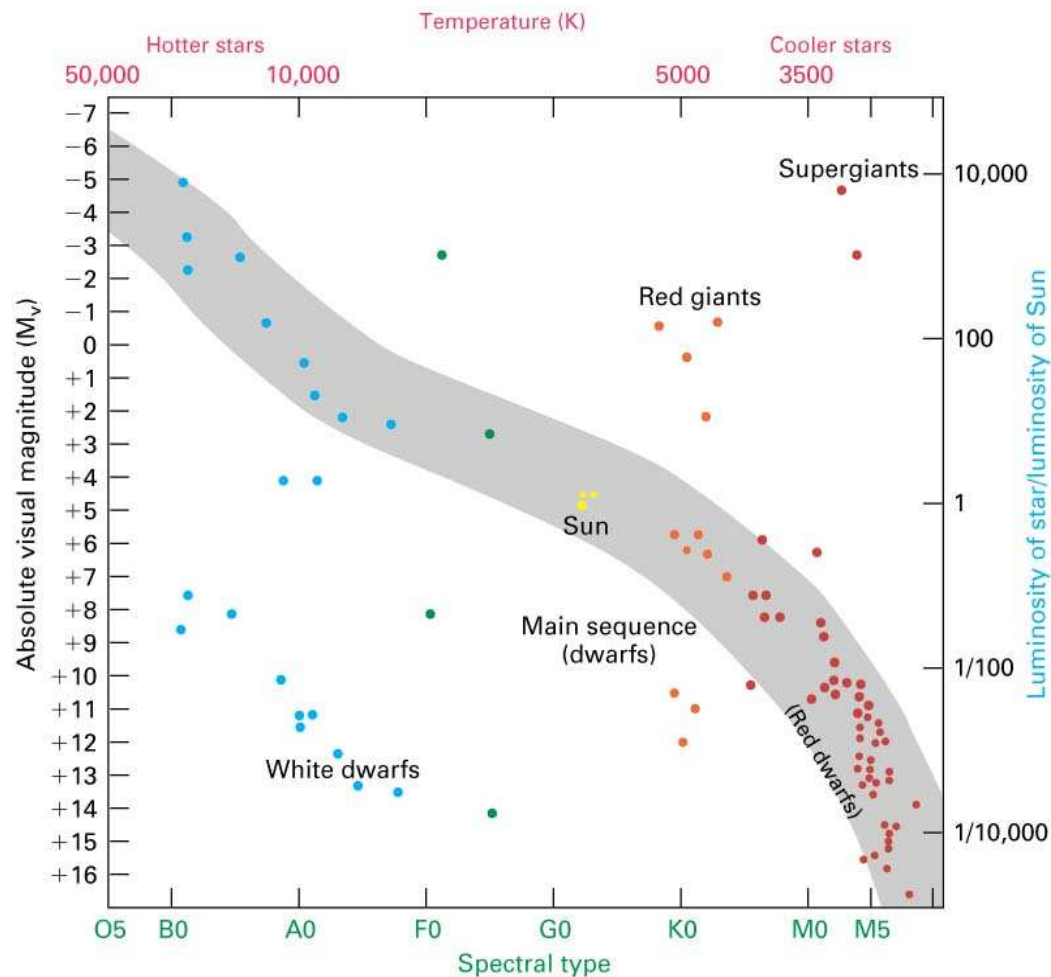
Norris Russell carried out procedure (1) and
Ejnar Herzsprung did it for stars in a cluster (2).

Their results are shown for a sample of stars – obtained by both methods:


Shaded area is called the
Main Sequence (MS)

On the MS the total luminosity
increases with increasing
mass.

White Dwarfs are hot , tiny
stars and Red Giants are cool
giant stars.

Mass can be estimated for stars which are in Binary systems.
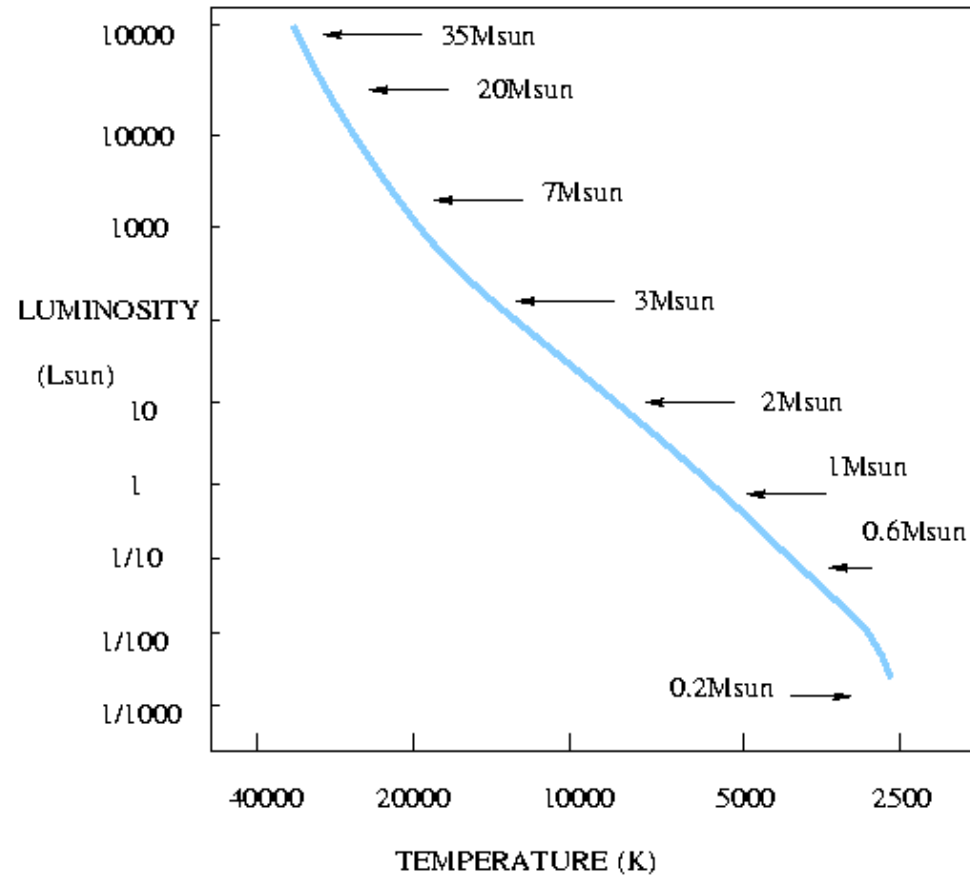
Measure the masses for as many stars as you can find in these systems and discover the **Mass-Luminosity relation for main-sequence stars.**
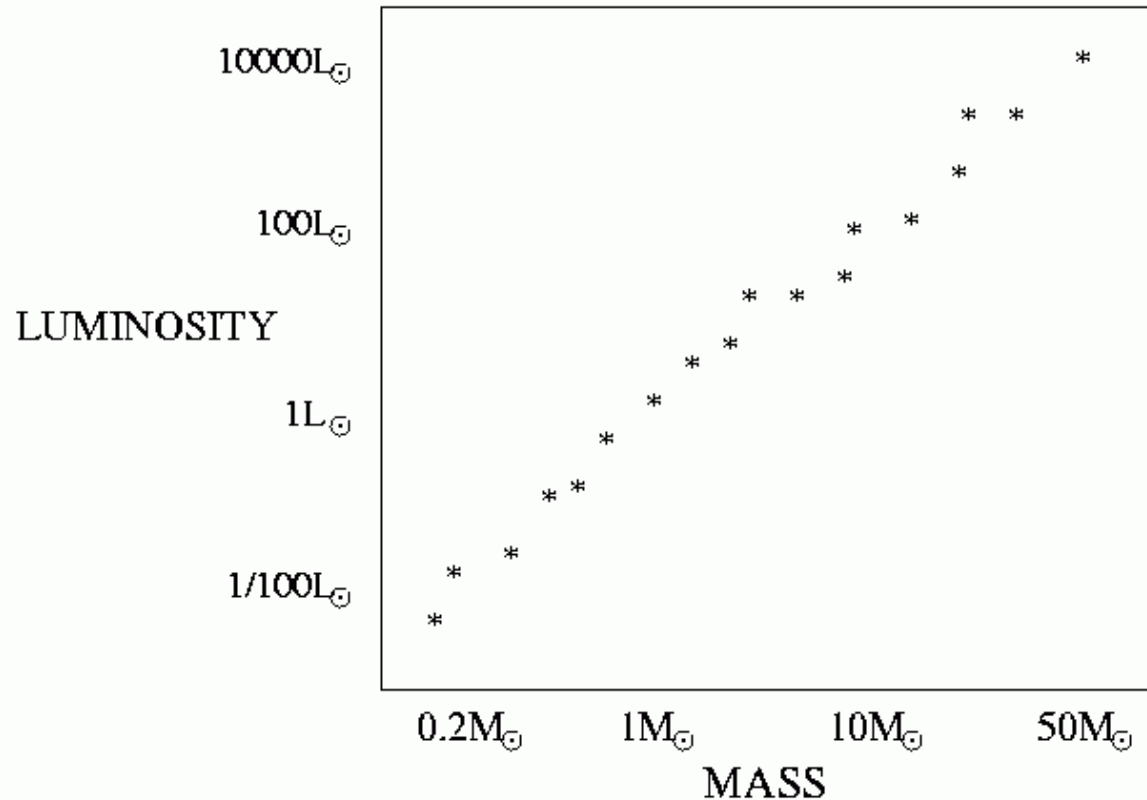
There is a pretty "steep" relationship between Mass and Luminosity in the sense that more massive stars are more luminous, thus

Mass of Main Sequence Stars

Note luminosity increases much more rapidly than increasing mass !

Radii of Stars:

With modern techniques of interferometry – use of multiple telescopes
to look at the same object in different wavelength regions – we can now
determine stellar radii of stars. If we know their color temperature
we can calculate their absolute luminosities with respect to that of the sun.

This is because luminosity is related to the power emitted per square meter
multiplied by the area of the star. And the power emitted per square meter
is proportional to the surface temperature raised to the 4th power !!
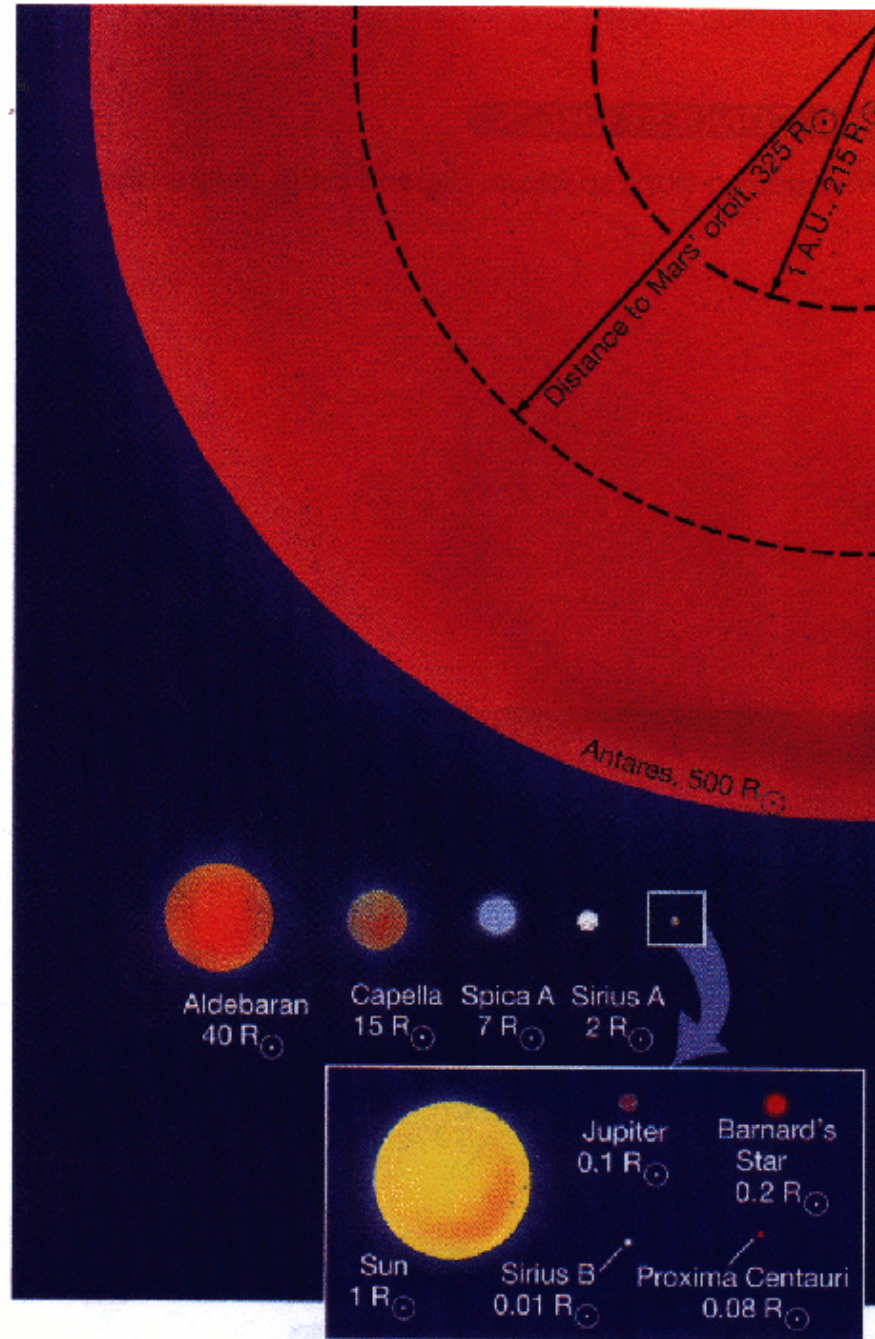
$$L = 4\pi R^2 \sigma T^4$$

where σ is a universal constant - Stefan Boltzmann constant

$$\frac{L_{star}}{L_{sun}} = \frac{R_{star}^2 \times T_{star}^4}{R_{sun}^2 \times T_{sun}^4}$$

Star Radii:

From red giants to
white dwarfs !

Red Super Giant Betelguese
would fill the entire
screen !

Clusters of Stars

Star Clusters are regions in our galaxy where many stars must have formed at about the same time – in a special star forming region.

There are two types of clusters:

1. Open Clusters are found in the Galactic Disk; typical cluster will have any number of stars from a few dozen to hundreds. Generally young stars and are not tightly bound.

2. Globular clusters (they look like a globule) have hundreds to thousands of stars which are tightly bound. They are made up of old stars and are generally found in the spherical halo surrounding the galactic center.

Cluster of stars were formed at the same time and out the same material.

Stellar evolution depends on the initial mass of the star – it is fast for massive stars and slow for smaller mass stars. Their HR diagram has valuable information about their history, in particular their age.

A property of the MS is that more massive stars are more luminous. More massive stars live a shorter life. So that if a **globular cluster is old they will have few massive stars on the MS.**

On the other hand open clusters are young and **should contain stars which are massive.**

I show an illustrations for both.

An old globular cluster of stars:

Globular Cluster G1 in Galaxy M31

HST · WFPC2

PRC96-11 · ST ScI OPO · April 24, 1996

Michael Rich, Kenneth Mighell, and James D. Neill (Columbia University),
Wendy Freedman (Carnegie Observatories) and NASA

Note that in the cluster stars are not of O or B type but older stars - look reddish
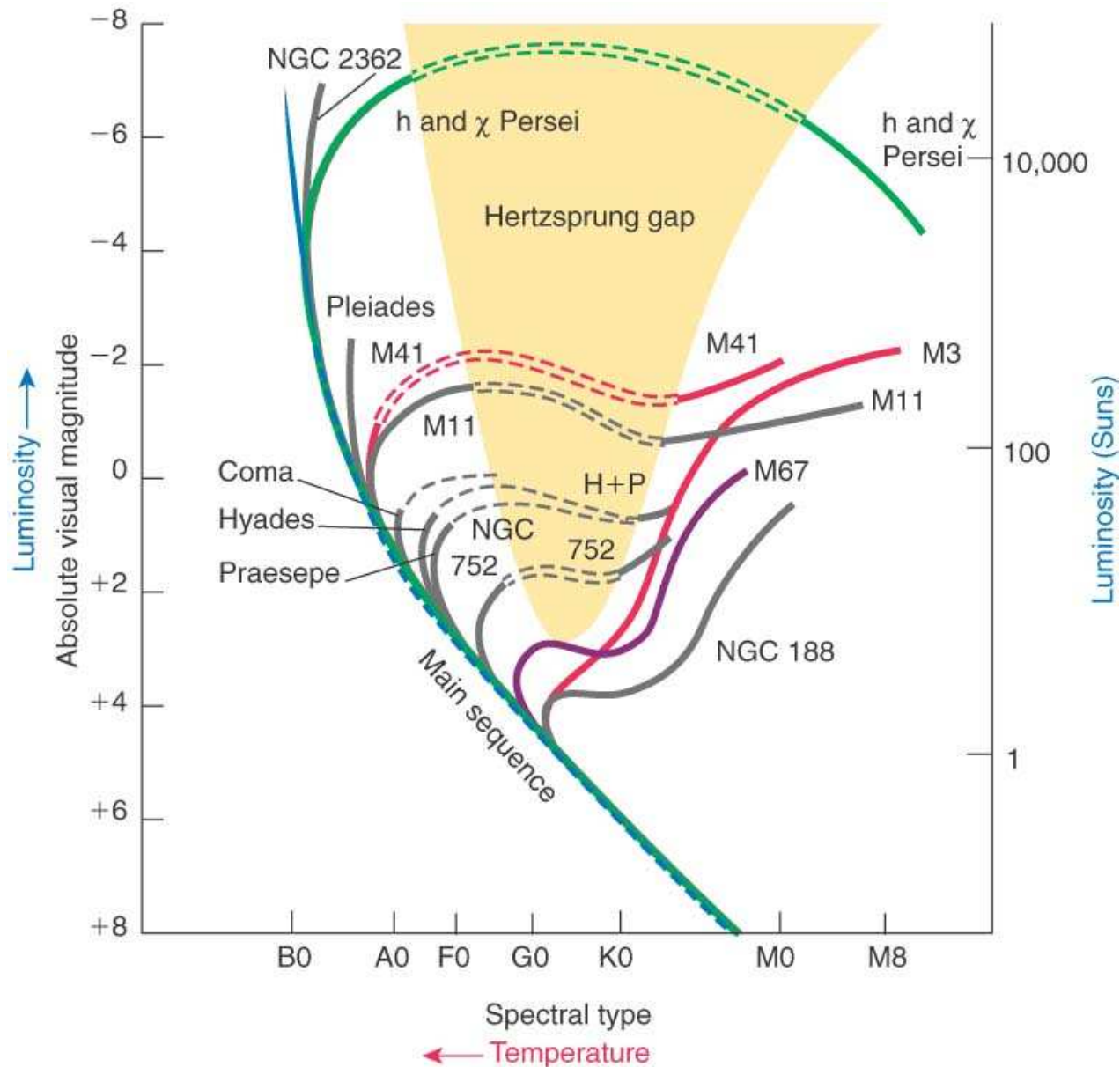
An open cluster of young stars surrounded by Rosetta nebula

Note the blue color for hot massive stars.

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HR tracks for stars in various clusters.

Very few stars in the dashed regions.

Turn off point determines the age of the cluster.

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How we measure basic stellar parameters is summarized
in the book : A Closer Look 11.5

Mass M: Usually from study of orbits of binary stars.

Size R: Usually from star's apparent brightness given its surface T and
      distance D

Luminosity L: From star's apparent magnitude, m, given its distance D

Rotation: From the Doppler shift broadening spectral lines

Surface Temp T: Spectral classification

Chemical composition: Detailed analysis of spectral lines

Determination of Stellar Properties – a summary

Property	Technique	Range of values
Distance	Trig Parallax	$1.3 \Rightarrow 80\text{pc}$
	Spect. Parallax	1 Mpc
Surface Temp.	Colors, Wein's Law Spectral Types	$3000\text{K} \Rightarrow 50000\text{K}$
Luminosity	Apparent brightness plus Distance*	$10^{-5} \Rightarrow 10^{6} \text{L}_{\odot}$
Radius	Stephan's Law	$0.01 R_{\odot} \Rightarrow 800 R_{\odot}$
Masses	Binary orbits	$0.08 M_{\odot} \Rightarrow 80 M_{\odot}$

Detecting Stellar movement:

1. Proper motions: Movement of a nearby star on the celestial sphere over time against the fixed distant stars. To get their projected speed needs the knowledge of their distance. For a given angular stellar position shift speed is small for a nearby star and large for a distant star. See figure 11-16.

2. Radial velocities of the stars with respect to us. This is measured spectroscopically. It arises from Doppler effect on wavelength (equivalently frequency) due to stellar motion towards or away from us.
   Observed wavelength is longer than emitted wavelength if the motion is away(red shift) and is shorter if the motion is towards. (blue shift).

Note: Change in pitch of a train whistle while approaching and receding from you is the analog in sound.
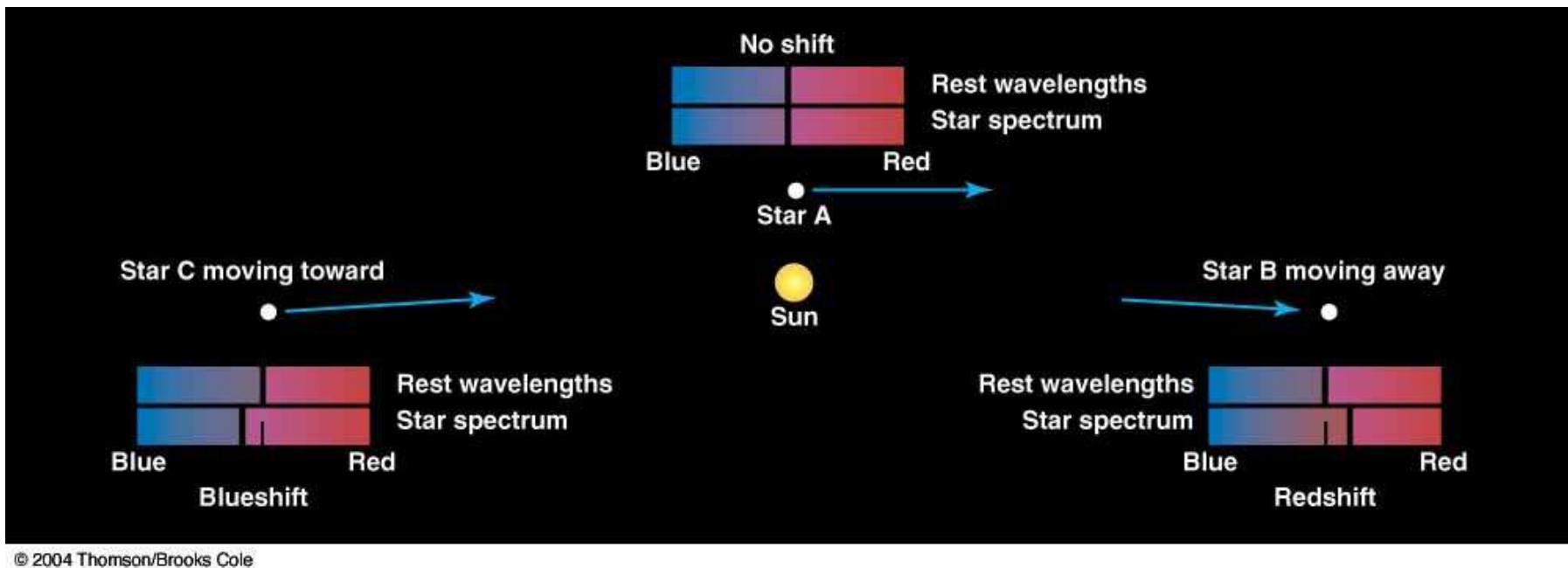
When the blue arrow is horizontal the star is not moving away or towards us and there is no shift observed.

For motion with some radial component there is a Doppler shift.

Doppler shift principles are shown in figure 11-17.

Determination of stellar mass: Use of binary system observations.

Section 11.6

Two stars when they rotate about each other, their motion can be seen by
1. Actual motion of two stars relative to each other. They have to be rather far apart to be able to see this.

2. A periodic change in brightness of stars if they eclipse (even partially) each other.

3. Spectroscopic binaries: Spectral lines move back and forth because of periodically changing Doppler effect.

If the mass of one of the stars is known the other can be estimated by using Newtonian version of Kepler's III law or at least a lower limit can be placed on the mass of the other star. This is how Black Holes have been identified.

Final Remark:

Mass of a star is the most important characteristic of a star. Its properties and its evolution depend on its Mass. (Although elemental composition also plays a role in some cases)

On the main sequence, stellar luminosity and stellar surface temperature increase rapidly as stellar mass increases.

Stellar lifetime $\qquad \text{Lifetime} \propto \dfrac{\text{stellar mass}}{\text{stellar luminosity}}$