# Chapter 6

## Measuring Stars

# Measuring Stars

6.1 Telescopes

6.2 Distances and motions of stars

6.3 Magnitude scales

6.4 Surface temperature of stars

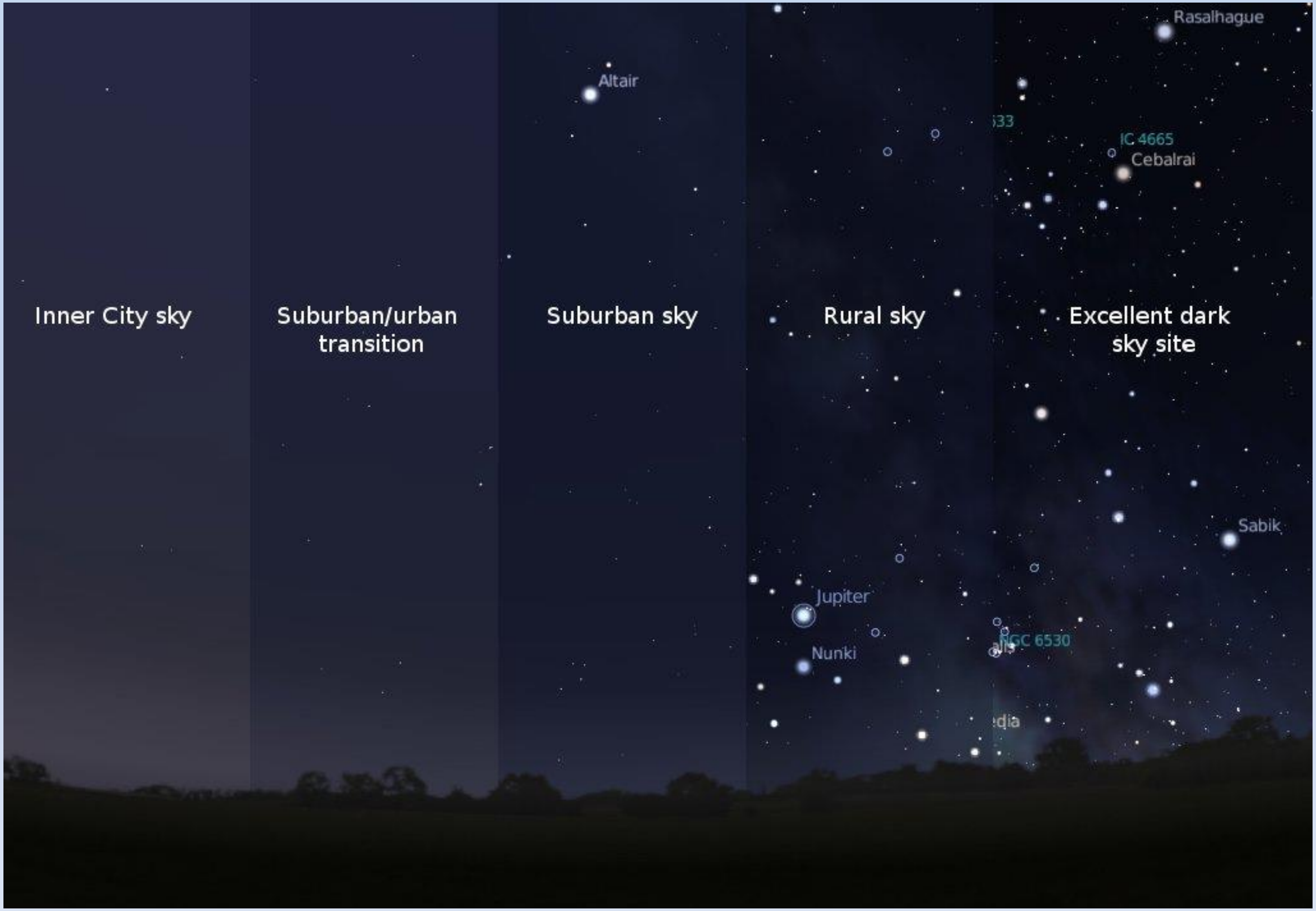
6.5 Physics of stellar spectra

6.5 Hertzsprung-Russell diagram

6.6 Binary stars

# 6.1 Telescopes

Image: Stellarium




Even without light pollution, some stars are too dim for us to see.

# 6.1 Telescopes

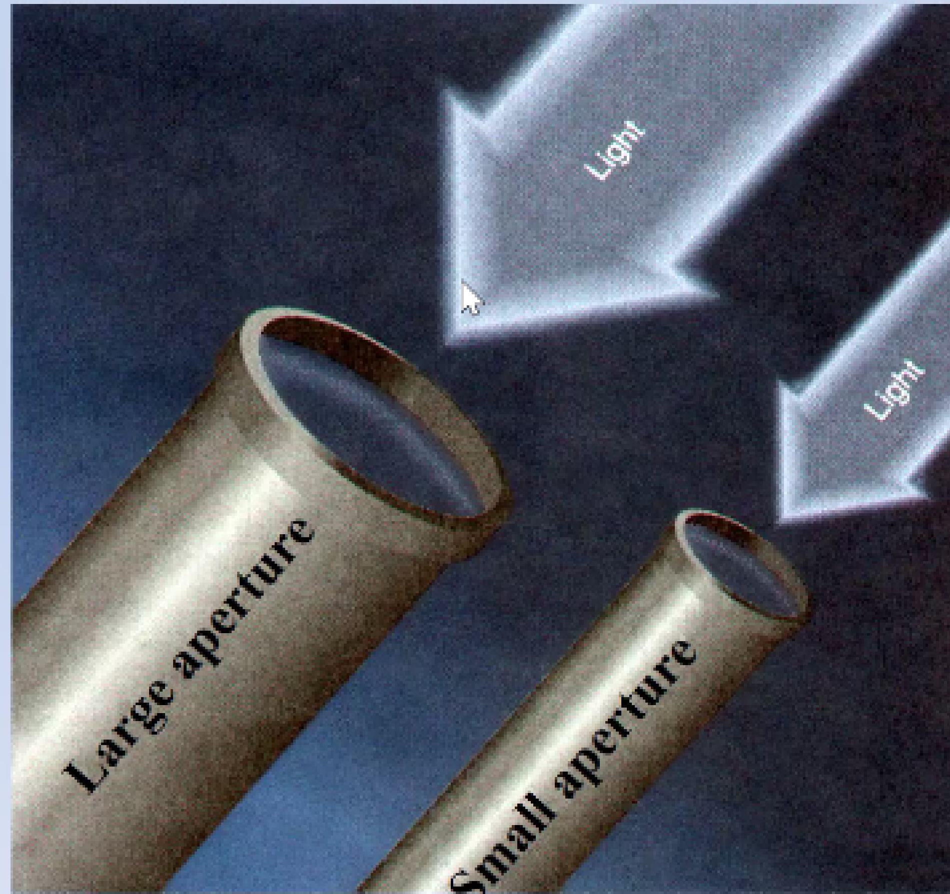
- ✓ Main purpose is for collecting light
  – basically a funnel of light (generally, EM radiation; or more generally, radiation or particle)

- ✓ The light-gathering power is directly proportional to the area of objective lens/mirror (thus fixed)

diameter of human pupil ~ 7 mm

Light collection power = $\left(\frac{lens\ diameter}{pupil\ diameter}\right)^2$

For example, for a 100-mm telescope, the images are ~ 204x brighter than naked eyes




A large aperture telescope can collect more light.

# Types of optical tubes

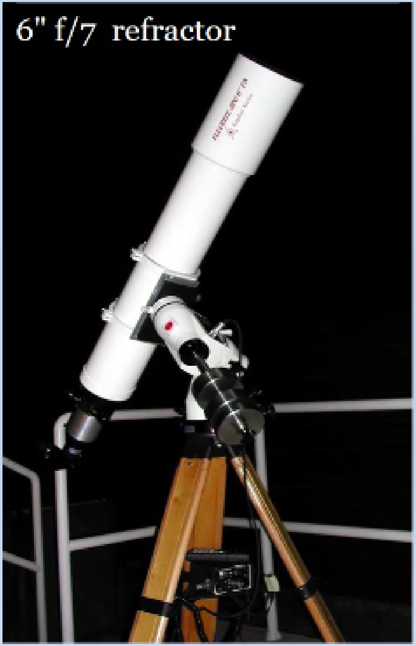
1. Refractors (折射式望遠鏡)
2. Reflectors (反射式望遠鏡)
3. Catadioptrics (折反式望遠鏡)

The biggest refractor in the world in Yerkes Observatory (USA), a telescope with an aperture of 102 cm.

The largest reflector in the world, Gran Telescopio Canarias (Spain), aperture 10.4 m.

Reflectors: The Hubble Space Telescope (HST), the first space telescope that was launched into low Earth orbit in 1990, aperture 2.4 m.


Catadioptric, aperture 8”

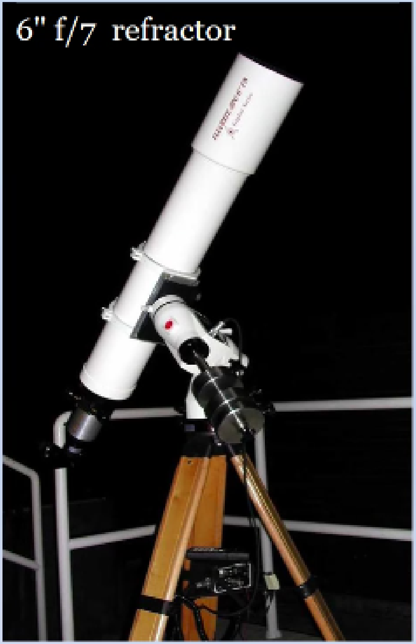



5" f/6 Newtonian reflector

$f$-number: $\frac{focal\ length,\ f}{diameter,\ d}$

6" f/7 APO refractor

diameter of the aperture = 6"



6" f/7 refractor

The focal length of the objective lens: 1000 mm (=6x25.4x7)

5" f/6 Newtonian reflector

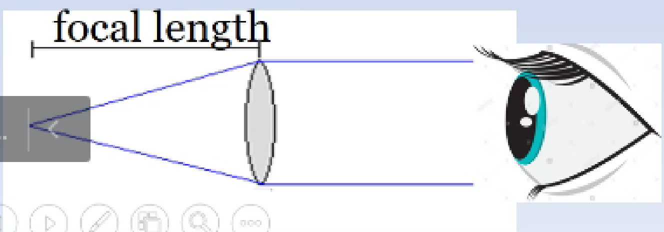
The focal length of the objective lens: 750 mm (=5x25.4x6)

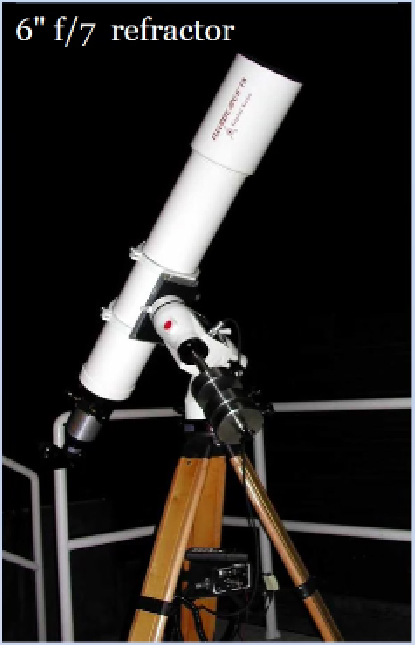

8" f/10 Schmidt-Cassegrain

The focal length of the objective lens: 2000 mm (=8x25.4x10)

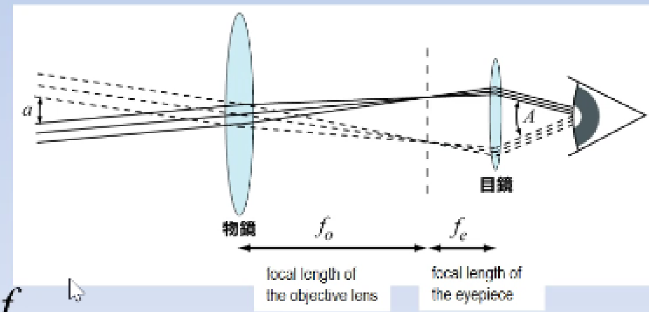
# Accessories

## Eyepieces






5" f/6 Newtonian reflector




Magnification: $m = \dfrac{A}{a} = \dfrac{f_o}{f_e}$

Magnification: $m = \frac{A}{a} = \frac{f_o}{f_e}$

For a 6" f/7 telescope, the focal length of the objective lens is 1000 mm, then

$m$ ~ 50 for a 20 mm eyepiece,

$m$ ~ 100 for a 10 mm eyepiece, and

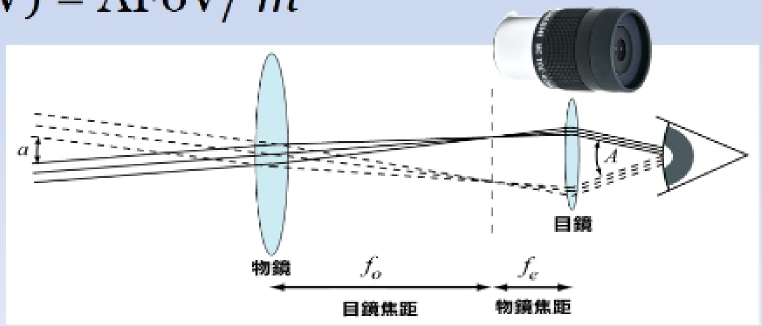
$m$ ~ 200 for a 5 mm eyepiece.

The shorter the focal length of a eyepiece, the larger the magnification is.

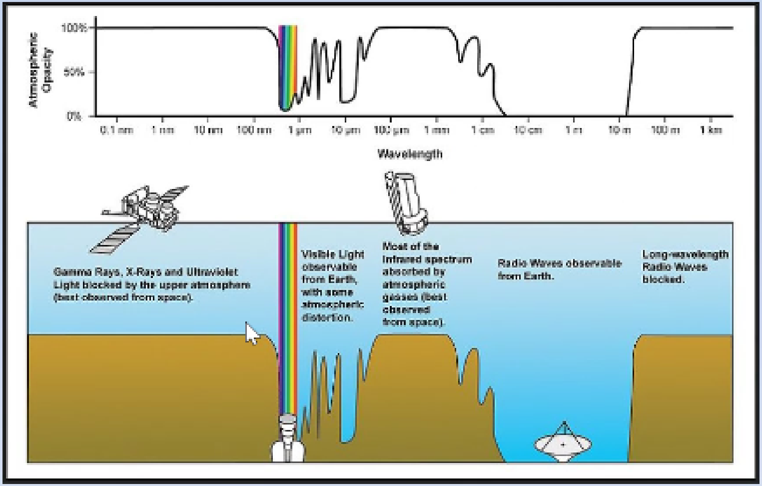
# Accessories

## Eyepieces

- commonly used: 5 mm, 10 mm, 15 mm
- Magnification: $m = f_o/f_e$, shorter focal length, larger magnification
- Apparent Field of View (AFoV) ~50° (typical); True FoV (TFoV) = AFoV/ $m$



# Receiving invisible light



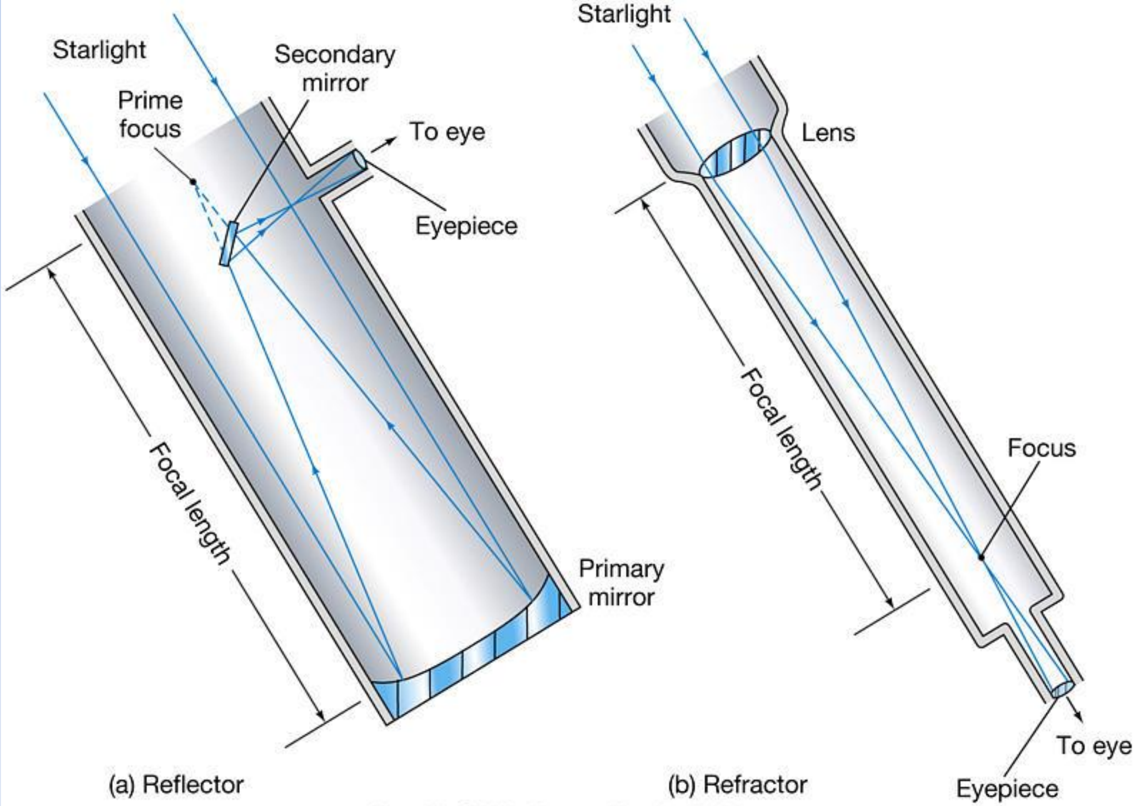

Infra-red, ultra-violet, and x-ray are easily absorbed by the atmosphere; infra-red is also absorbed by water.

To receive those signals, telescopes are built on dry regions, high mountains, or in the space.

# 6.1 Telescopes

- ✓ Magnification
  = (apparent angular size)/(real angular size)
- ✓ can be changed by replacing the eyepiece

Here are two of the different designs to focus light for optical telescope.



# 6.1 Telescopes

- Angular resolution: ability to resolve fine details
- In a lot of situations, the resolving power depends on the atmospheric condition (the "seeing")

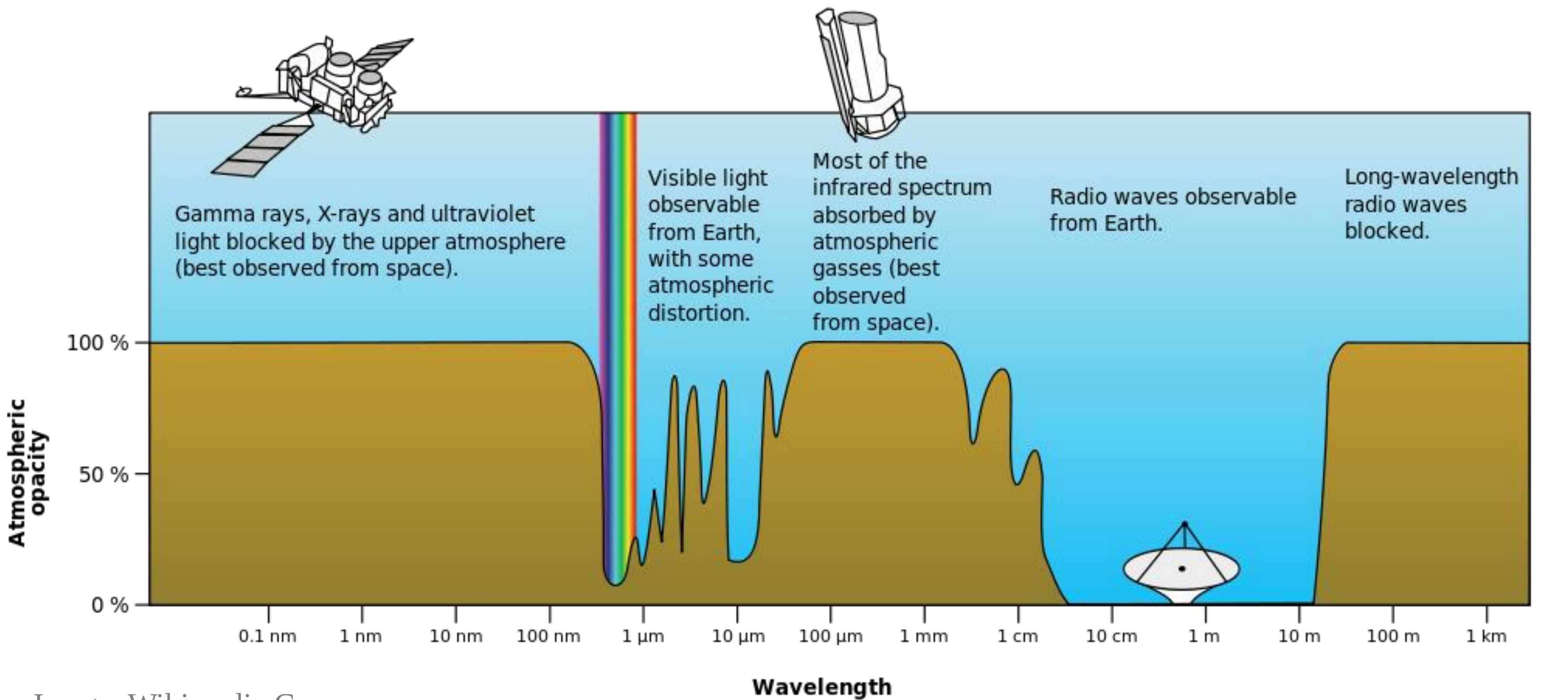



Image: Wikimedia Commons

# 6.1 Telescopes

- ✓ Water vapor is the main culprit at a lot of wavelength
- ✓ Need to place them at dry location, …

ALMA, 5000m above sea level, in Chile

Image: ESO/NAOJ/NRAO

South Pole Telescope

Image: U of Chicago

# 6.1 Telescopes

- ✓ or up in the sky or even space (necessary for UV, X-ray, gamma ray, …)

SOFIA in flight


Image: NASA

Hubble Space Telescope

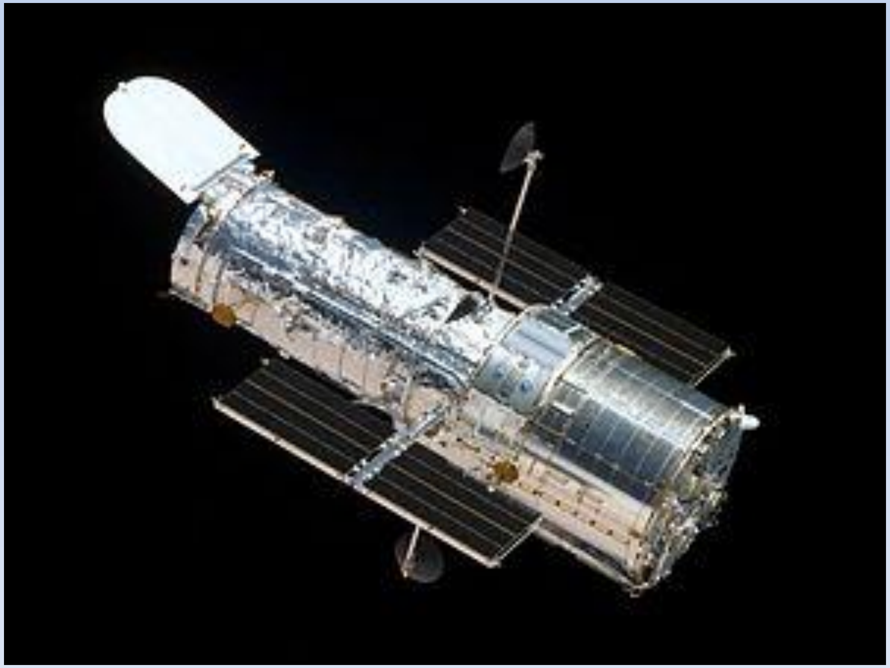


Image: NASA

# 6.1 Telescopes

- ✓ or by doing some tricks.

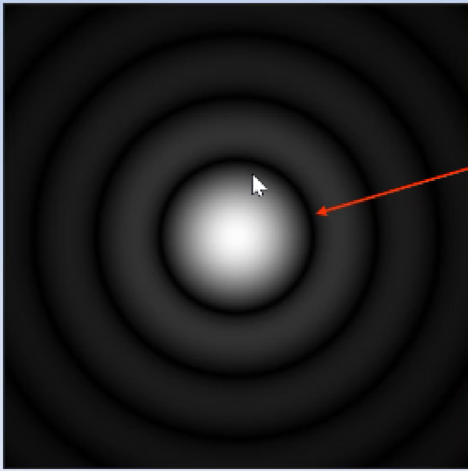
Using adaptive optics with VLT

Image: ESO

# Limitations: Resolving power of a telescope

- Finite size of a telescope's aperture leads to diffraction of light.

The image of a point source.

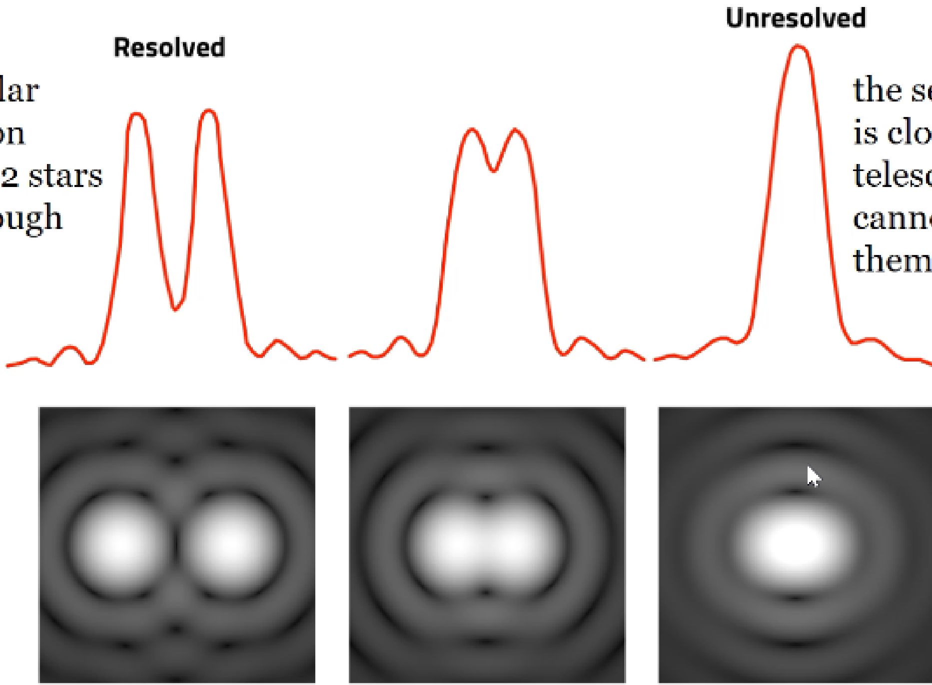


Airy disk (艾里斑)

Image: Wikimedia Commons

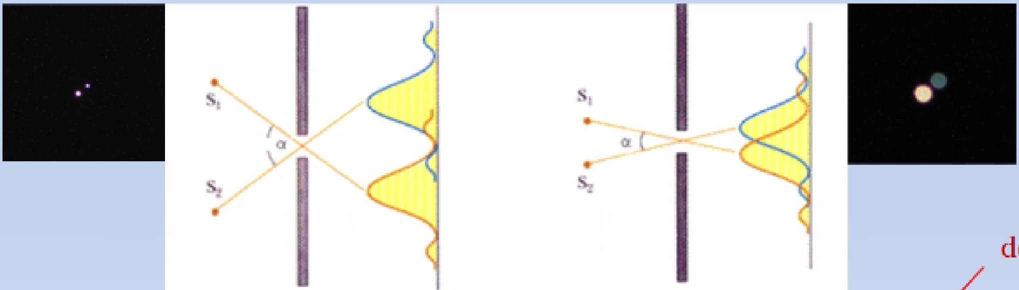
# Limitations: Resolving power of a telescope

the angular separation between 2 stars is far enough




the separation is close, a telescope cannot resolve them.

# Limitations: Resolving power of a telescope




If the angular separation between 2 stars is far enough, a telescope can resolve them

derivation omitted.

However, if the separation is close, a telescope might not resolve them. Theoretically, the resolving power of a telescope: $\alpha = 1.22\lambda/d$ (in radian)
For $\lambda$ = 550 nm, the resolution of a 0.3m aperture telescope ~ 0.47 arcseconds.

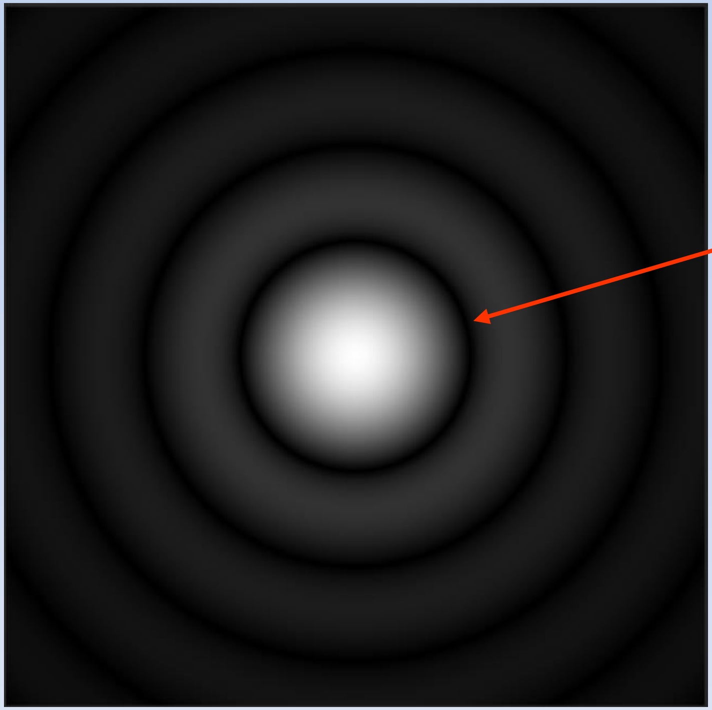
arc second：弧秒；角秒（等于second，arc-second）

# 6.1 Telescopes

- ✓ Yet, there is a limit of the angular resolution.
- ✓ Finite size of a telescope's aperture leads to diffraction of light.
- ✓ Can't resolve two sources if their Airy disks overlap
- ✓ Rayleigh criterion:

$$\theta = 1.22 \frac{\lambda}{D}$$

where $D$ is diameter of the telescope's aperture



Airy disk

Image: Wikimedia Commons

# 6.1 Telescopes

✓ There's a trick to increase effective aperture.

Interferometry

VLA

VLBI

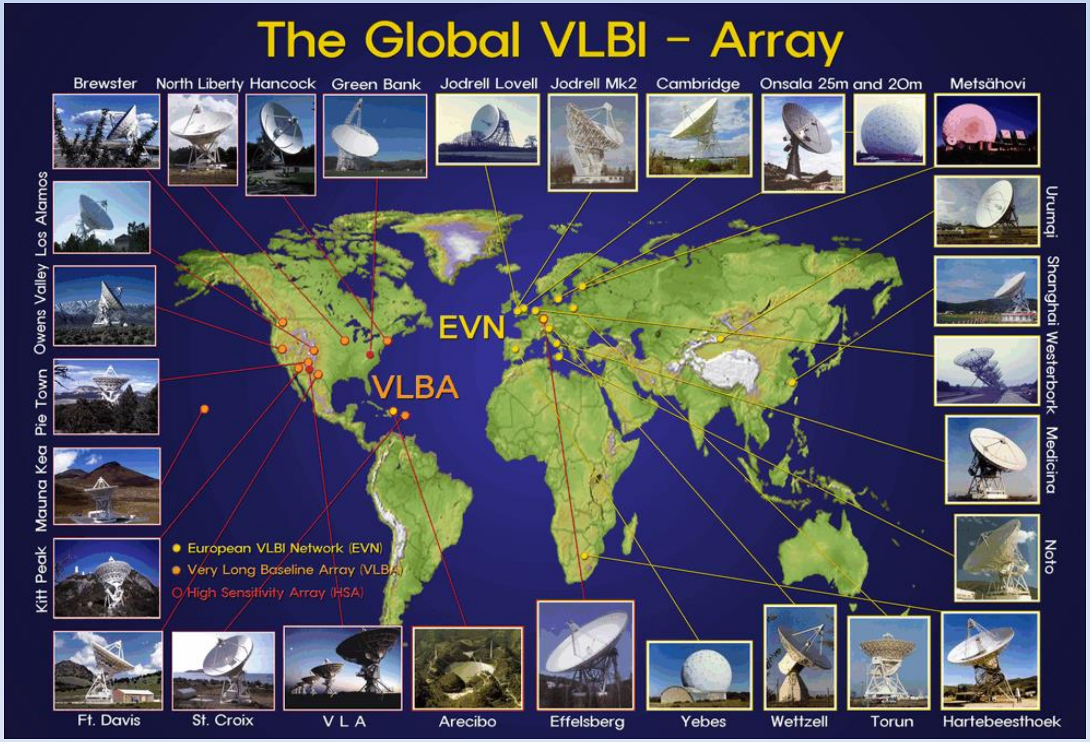
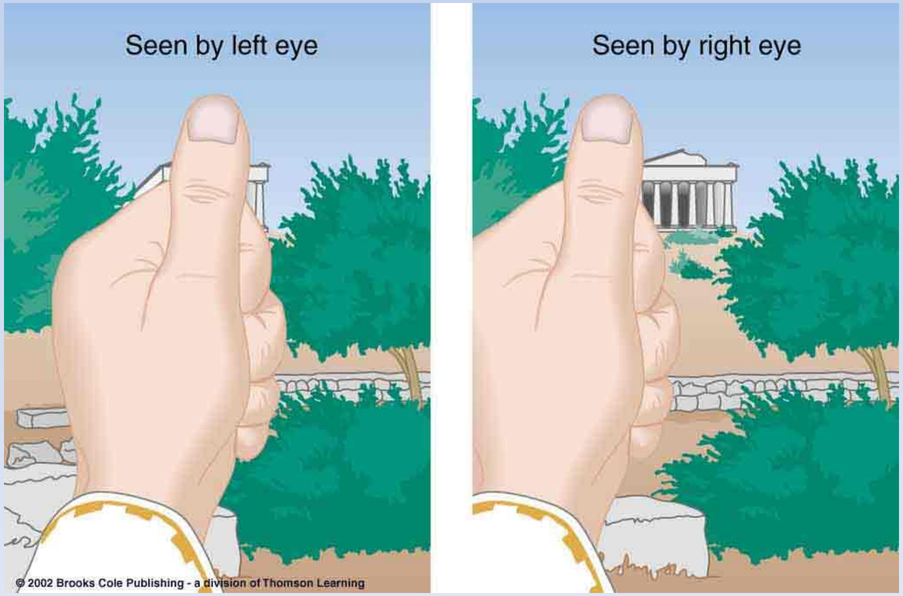


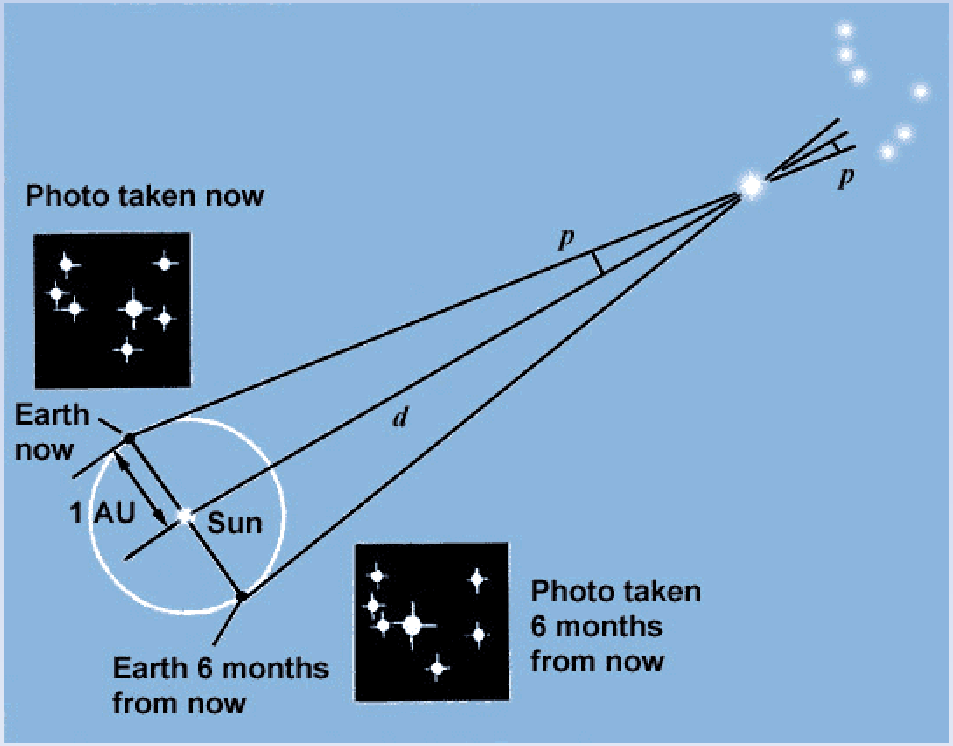

Image: NRAO/AUI

# 6.2 Distances and motions of stars

## Method of parallax (aka Stellar parallax)

- ✓ Earth moves around the Sun → observed from Earth, a nearby star appears to move in an ellipse in a year
- ✓ Apparent position change depends on its distance from Earth



# 6.2 Distances and motions of stars

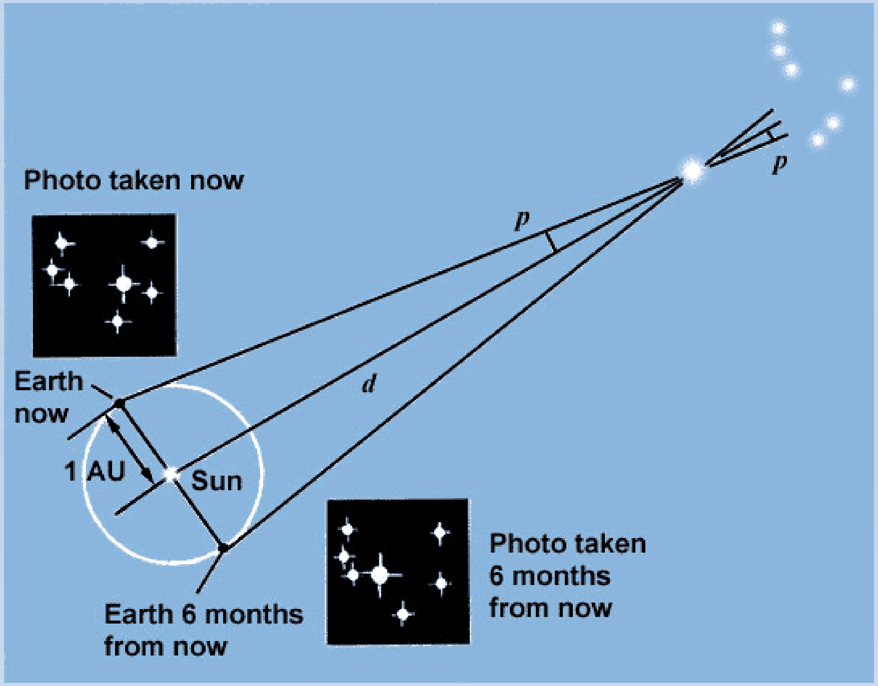
## Method of parallax

- ✓ Parallax $p$: half of the total shift in the angular position of a star.

  $$d = 1/p$$

- ✓ Angle $p$ is in arc-second; distance $d$ is in parsec

  $$1\,\mathrm{pc} = 206265\,\mathrm{AU} \approx 3.26\,\mathrm{ly}$$



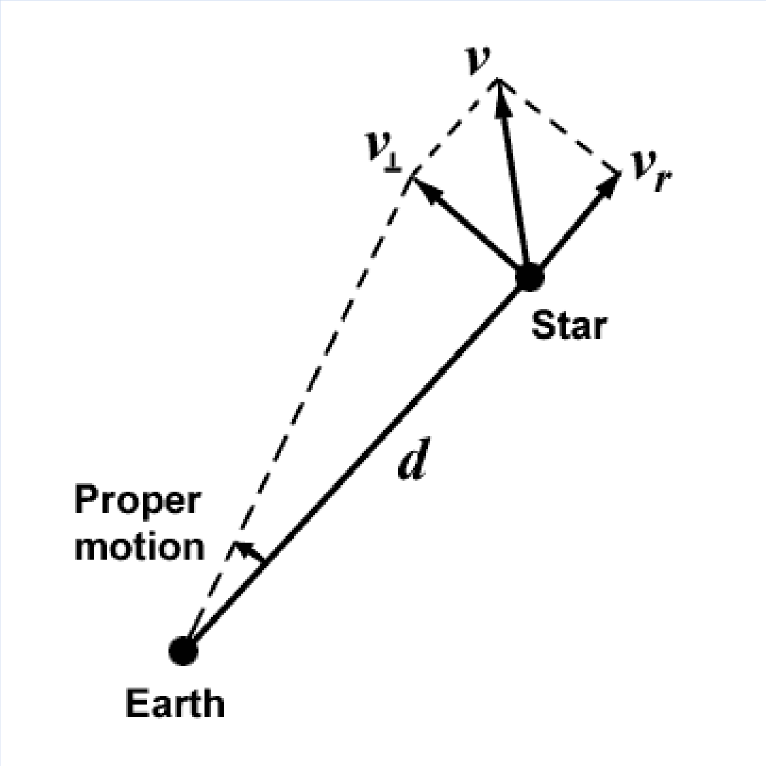

- ✓ Earth's atmosphere limits the angular resolution
- ✓ Farthest star measured by this method ~ 100 pc

  (space-based Hipparcos (1989) measured distance up to ~ 1600 pc, Gaia (2013) up to ~ $10^7$ pc)

# 6.2 Distances and motions of stars

## Stellar Motions

- ✓ Star moves very slowly in the sky.
- ✓ Velocity can be broken into components parallel and perpendicular to our line of sight.
- ✓ The component perpendicular to our line of sight, also known as the tangential velocity $v_\perp$ , is related to the proper motion.



# 6.2 Distances and motions of stars

## Stellar Motions

- ✓ Proper motion ($\mu$): the change in the angular position in one year
- ✓ The tangential velocity $v_{\perp}$, in km/s is given by

$$v_{\perp} = 4.74\ \mu \times d,$$

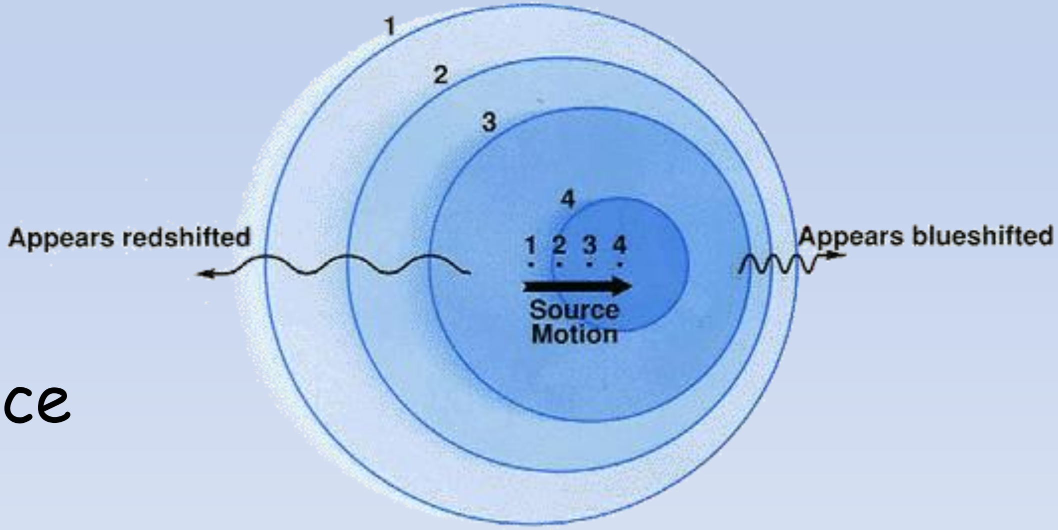
where $\mu$ measured in arcseconds; in $d$ parsecs

- ✓ The radial component of a star's motion parallel to our line of sign is its radial velocity $v_{\mathrm{r}}$
- ✓ Determined by the Doppler shifts of the star's spectral lines.

# Box 6.1 Doppler effect

✓Waves get compressed in the direction of motion the source, wavelength smaller, frequency higher; hence called blue shifted

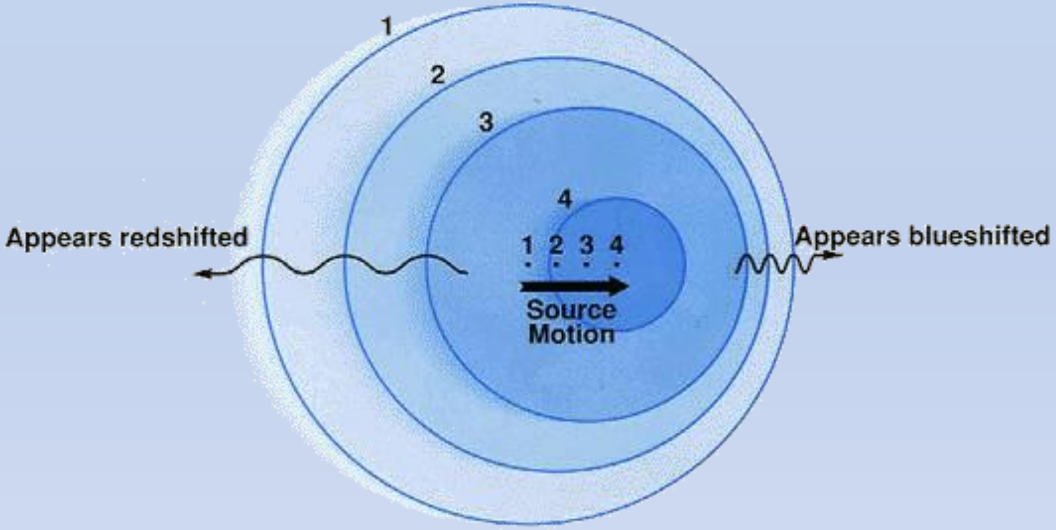
✓Opposite effect observed behind the source. That is, wavelength longer, frequency lower; hence called red shifted



# Box 6.1 Doppler effect

✓For a wave propagating in a medium

$$\lambda = \left(\frac{c + v_s}{c - v_r}\right)\lambda_0$$




✓For light, if $v \sim c$,

$$\lambda = \lambda_0 \sqrt{\frac{1 + v/c}{1 - v/c}}$$

which reduces to the classical equation for smaller velocity.

# 6.3 Magnitude scales

- ✓ Luminosity $L$: defined total radiation energy (all wavelengths) **emitted** by a star per unit time (unit W). For the Sun, $L_{\odot} = 3.90 \times 10^{26}$ W
- ✓ Apparent Brightness $B(r)$: amount of light energy **received** per unit time per unit area at a distance $r$ from the star, (unit W m$^{-2}$). Also known as flux.
- ✓ Inverse-Square Law:

$$B(r) = \frac{L}{4\pi r^2}$$

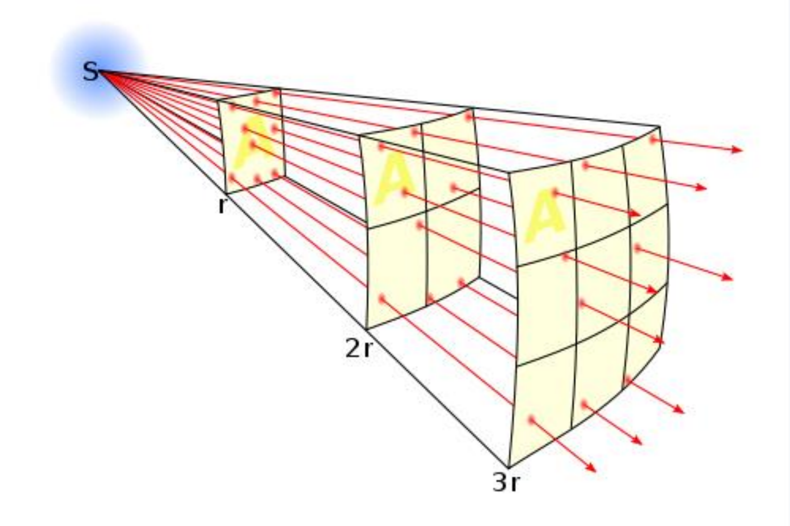



Image: Wikimedia Commons

# 6.3 Magnitude scales

- ✓ Apparent magnitude $m$ : measure a star's brightness compared with a reference star, Vega

$$m = -2.5\log\left(B / B_{\mathrm{Vega}}\right)$$

apparent magnitude of the reference star, $m_{\mathrm{Vega}} = 0$

- ✓ *does not* measure the star's intrinsic luminosity
- ✓ The magnitude difference: $m_1 - m_2 = -2.5\log\left(B_1 / B_2\right)$

For example, 5 magnitudes ~ 100 times in brightness.

# 6.3 Magnitude scales

- Absolute Magnitude $M$ : Magnitude measured *as if* the star was at a distance of 10 pc from the Earth.
- By Inverse-Square Law:

$$B(r)/B(10) = 10^2/r^2$$

$$\log\left[B(r)/B(10)\right] = 2 - 2\log r,$$

where the distance $r$ is measured in pc. Hence, the distance modulus is $m - M = -5 + 5\log r$

- *can* measure the star's intrinsic luminosity
- Bolometric magnitude: consider the whole spectrum

# 6.4 Surface temperature of stars

Why do stars have different colours?

e.g., reddish Betelgeuse (獵戶 $\alpha$), and bluish Bellatrix (獵戶 $\gamma$)

✓ The colour reveals a star's surface temperature. But how are they related?

# 6.4 Surface temperature of stars

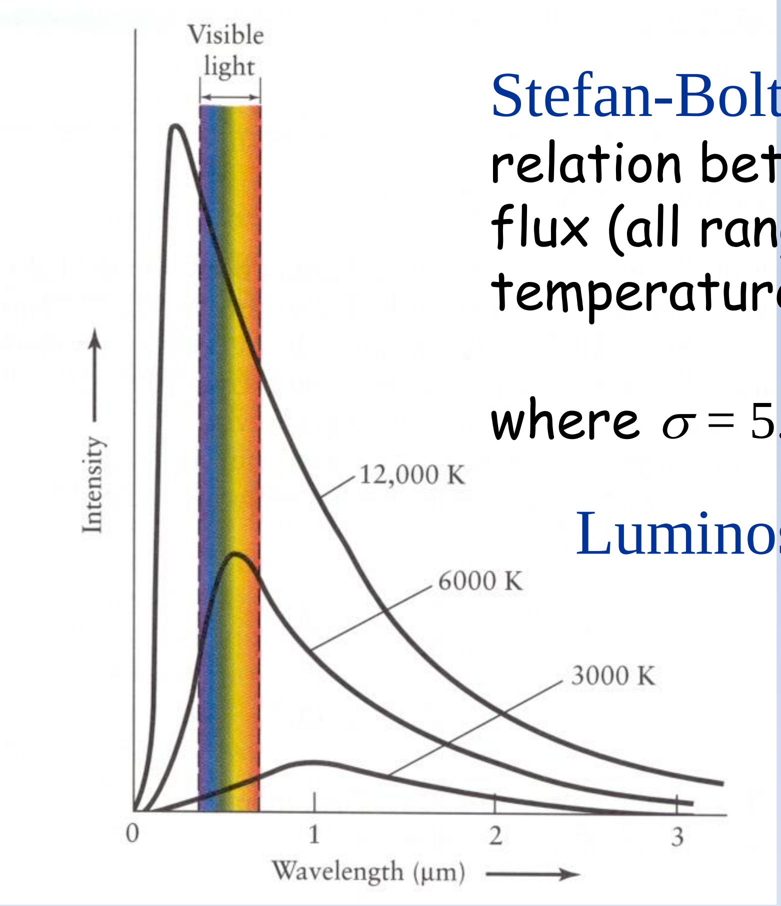
- ✓ In the star's core, nuclear reactions takes place and emits high-energy radiations, e.g., $\gamma$-rays
- ✓ The radiation absorbed and re-emitted inside the Sun. It takes about $10^5$ years for the radiation to reach the surface!!
- ✓ Deep into a star, atoms fully ionized in a state of *plasma*
- ✓ Because of collisions of charged particles and photons, a continuous spectrum (EM waves of continuous wavelengths) observed, like blackbody radiation

# Revision: blackbody radiation

Wien's law: relation between the wavelength at max emission and the temperature

$$\lambda_{max} = \frac{0.0029}{T}$$

where $\lambda_{max}$ in meter; $T$ in K




Stefan-Boltzmann law: relation between the energy flux (all ranges of $\lambda$) and its temperature

$$F = \sigma T^4$$

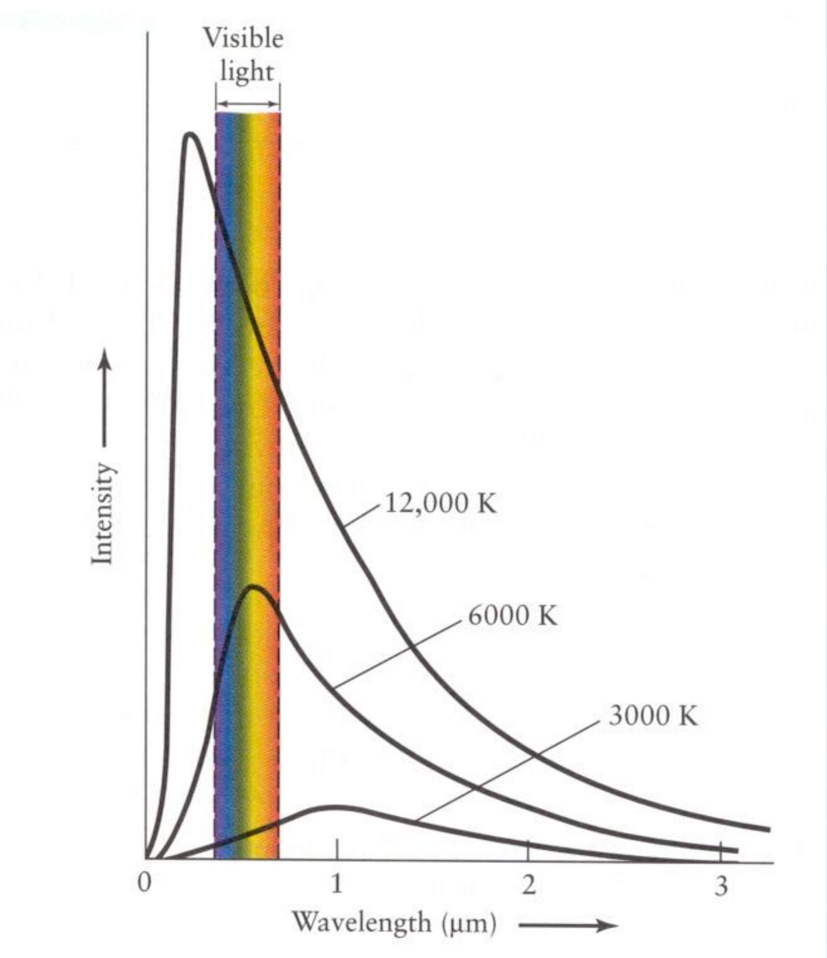
where $\sigma = 5.67 \times 10^{-8}$ W m$^{-2}$ K$^{-4}$

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

✓ Shape of spectrum depends on its temperature

# 6.4 Surface temperature of stars

- ✓ According to Wien's law, blue stars are of higher surface temperatures than red stars
- ✓ the shape of spectrum depends on its temperature; hence, it is revealed by comparing the relative intensity in neighboring wavelength bands



# 6.4 Surface temperature of stars

UBV photometric system :

- ✓ there are lots of info in different wavelengths of the EM signal
- ✓ brightness is measured in passbands - frequency ranges allowed selectively by certain filters

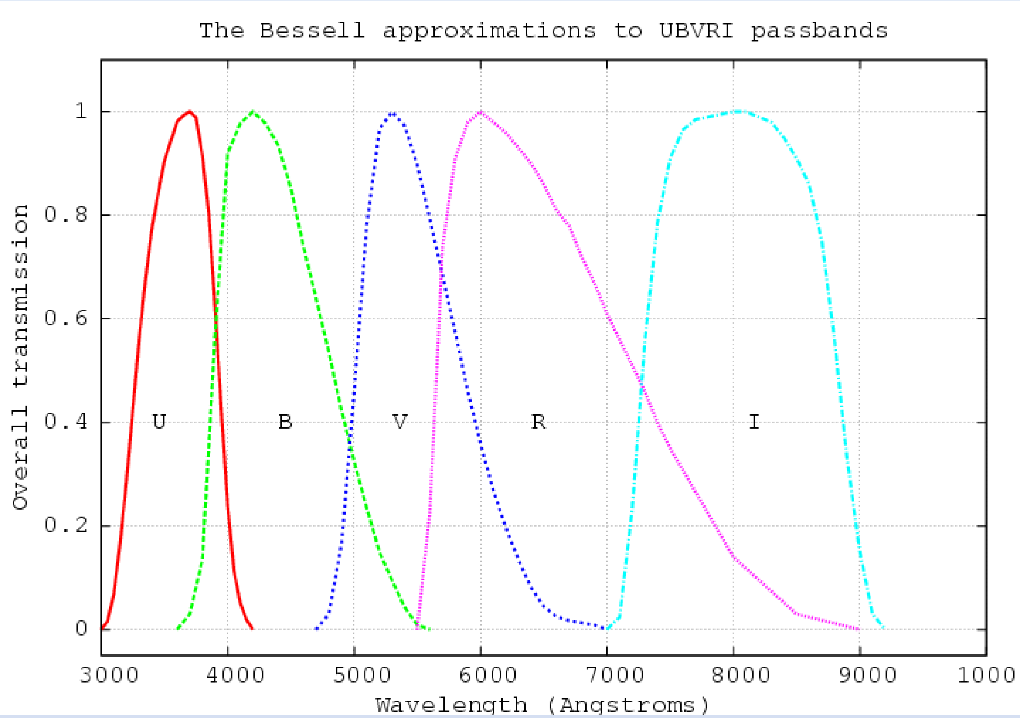
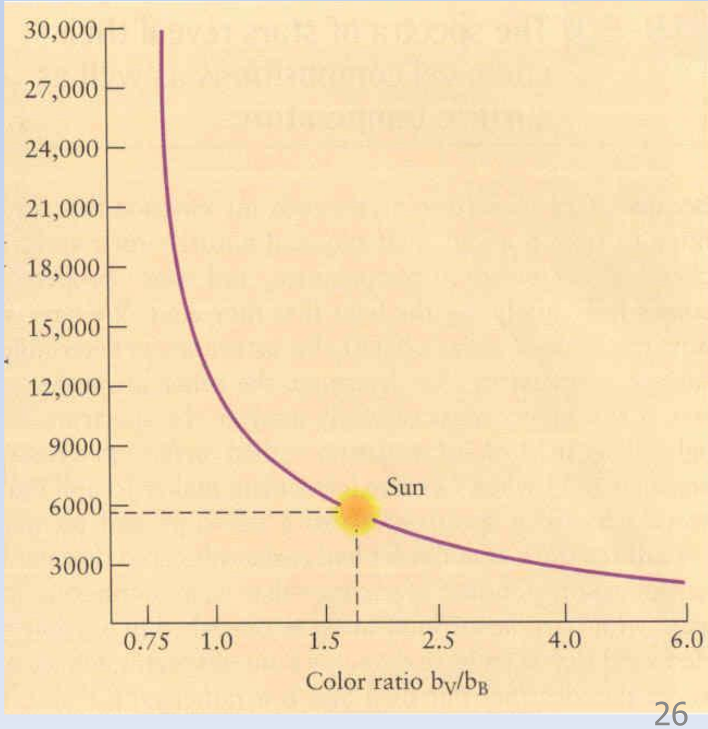



Image: RIT

# 6.4 Surface temperature of stars

UBV photometric system :

- ✓ A common technique to measure surface temperature
- ✓ measure apparent brightness in 3 passbands: **U**-band (ultraviolet, $b_U$), **B**-band (blue, $b_B$) and **V**-band (visual, peak at yellow, $b_V$)
- ✓ Colour ratios $b_V/b_B$ and $b_B/b_U$ indicate surface temperature. For the Sun, $b_V/b_B = 1.77$ and $b_B/b_U = 1.10$, corresponds to $T = 5800\text{K}$
- ✓ Similarly, we can use the magnitudes to define the colour difference B-V and U-B



# 6.5 Physics of stellar spectra

How could we know the physical nature of a star, e.g., temperature, structure, chemical composition, etc.?

✓ Stars are so distant, only information we can measure is the *spectra of stars*

# 6.5 Physics of stellar spectra

- ✓ Continuous blackbody spectrum

  – produced at low-lying levels of the stars where the gases are relatively hot and dense

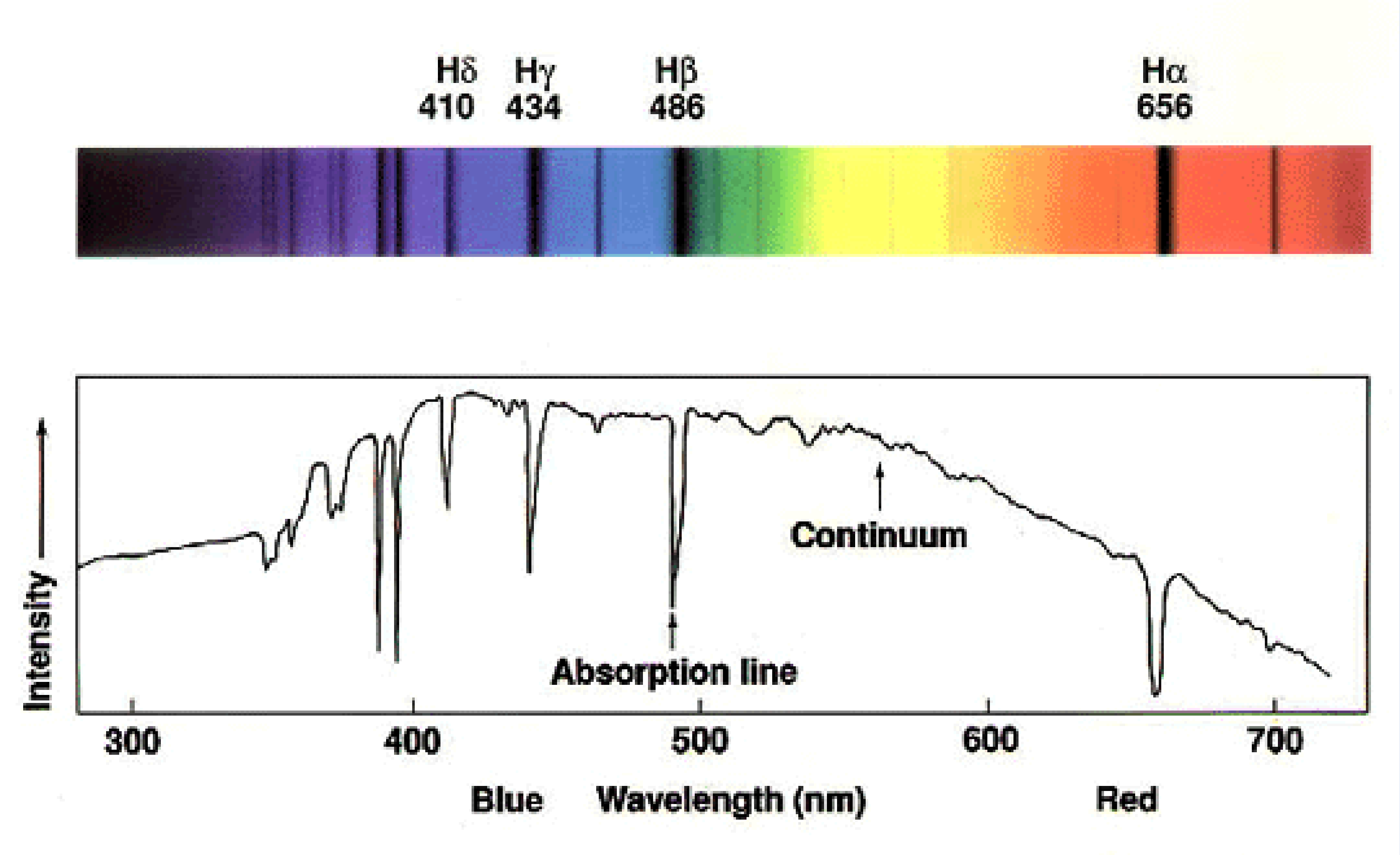
- ✓ Absorption lines

  – produced when continuum radiation flows outward through *the cooler, less dense, upper layers of star's atmosphere*. Atoms in the upper layers absorbs radiation at specific wavelengths;

  - hence, the spectra can tell what the elements are and their temperature

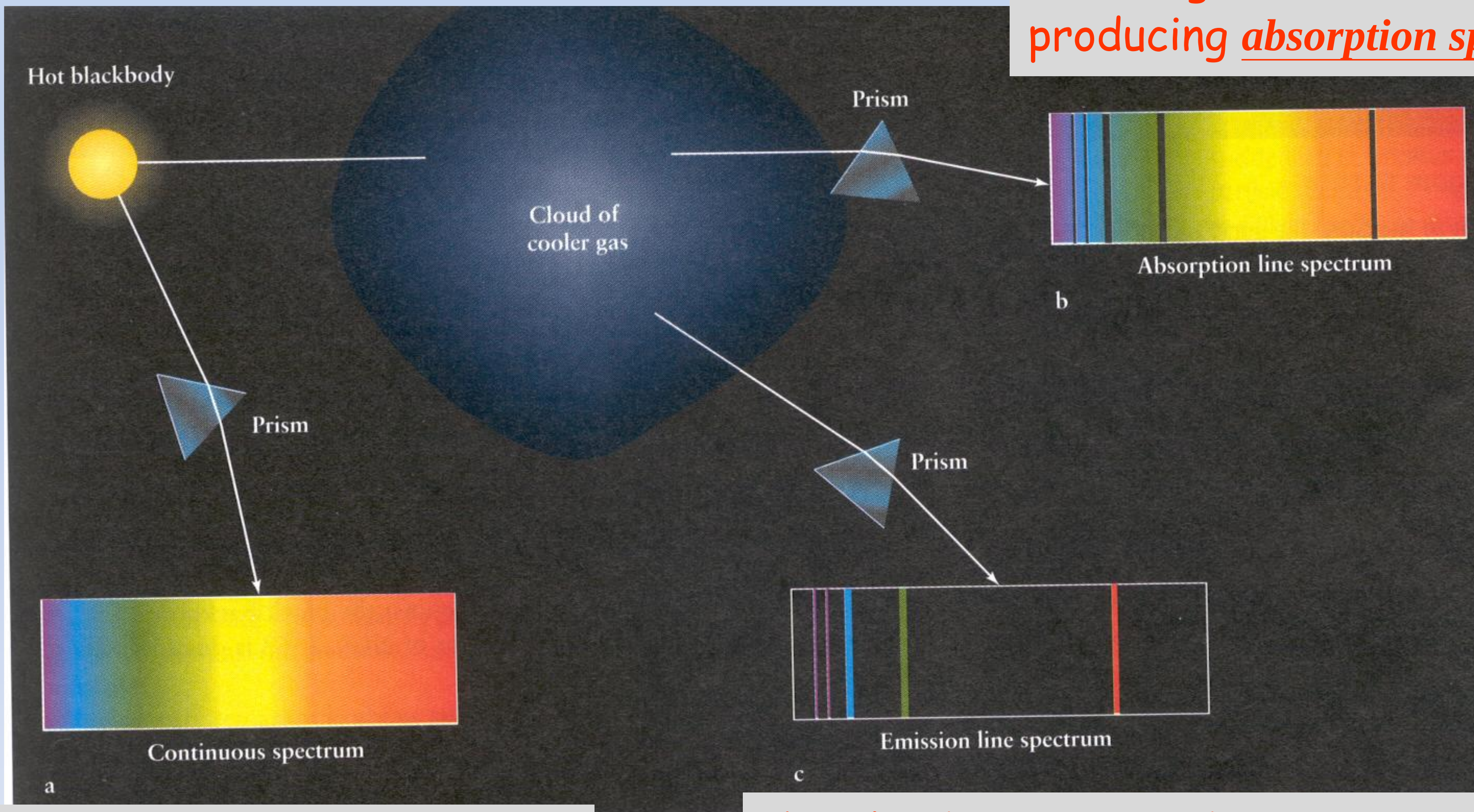
# 6.5 Physics of stellar spectra

吸收光谱



# Box 6.2 Types of Spectra

passing through cloud of cool gas, certain wavelengths are absorbed, producing ***absorption spectrum***




hot, glowing object produces a ***continuous spectrum*** of light

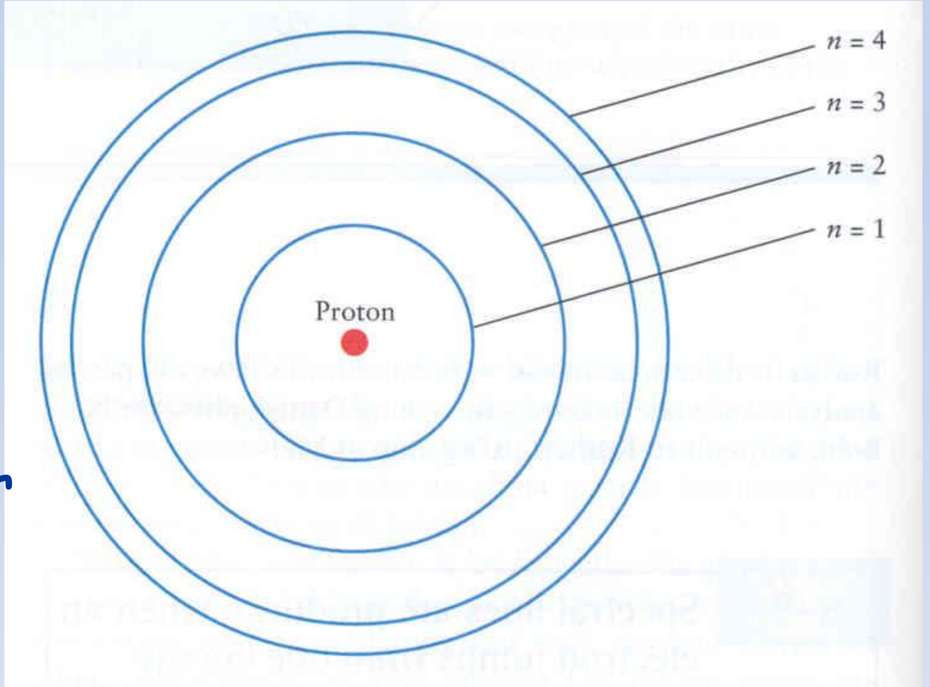
the cloud absorbs and re-emits radiation of specific wavelengths. Observe ***emission spectrum*** against dark background

# Box 6.2 Types of Spectra

## Bohr Model of atom

✓Photon absorbed when an electron jumps from lower energy orbit to another higher energy orbit

✓Photon emitted when an electron jumps from higher energy orbit to another lower energy orbit



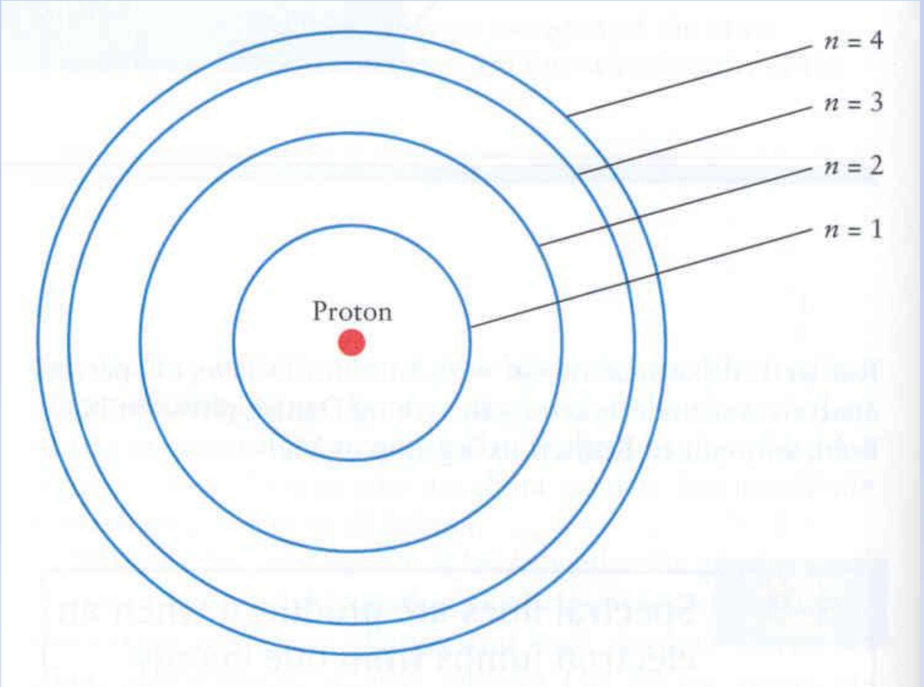
## Box 6.2 Types of Spectra

### Bohr Model of atom

✓For hydrogen atom, wavelength of absorbed or emitted radiation is given by

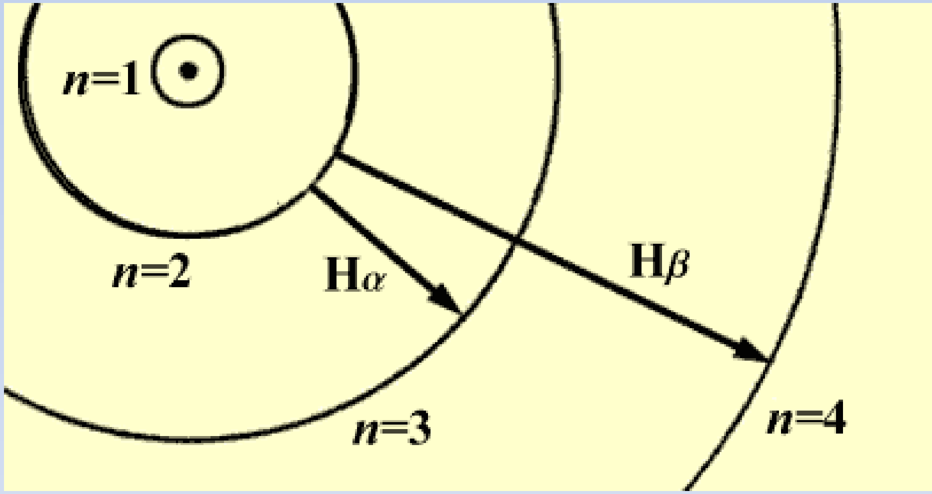
$$\frac{1}{\lambda} = R\left(\frac{1}{N^2} - \frac{1}{n^2}\right)$$

$R = 1.097\times10^{7}\ \mathrm{m}^{-1}$, $N$ is the number of inner orbit, and $n$ is the number of outer orbit.



# Box 6.2 Types of Spectra

- ✓If electron transition between the 2nd orbit ($N = 2$) and a higher orbit, it is *Balmer series*, e.g., $n = 3$ ($H_\alpha$, $\lambda \sim 656.3$ nm ); $n = 4$ ($H_\beta$, $\lambda \sim 486.2$ nm).
- ✓If electron transition between the 1st orbit ($N = 1$) and a higher orbit, it is *Lyman series* (ultraviolet)
- ✓If electron transition between the 3rd orbit ($N = 3$) and a higher orbit, it is *Paschen series* (infrared)



# 6.5 Physics of stellar spectra

## Harvard spectral classification

According to star's surface temperature, spectra classified into 7 *spectral classes*

**O**h! **B**e **A** **F**ine **G**irl (**G**uy) **K**iss **M**e

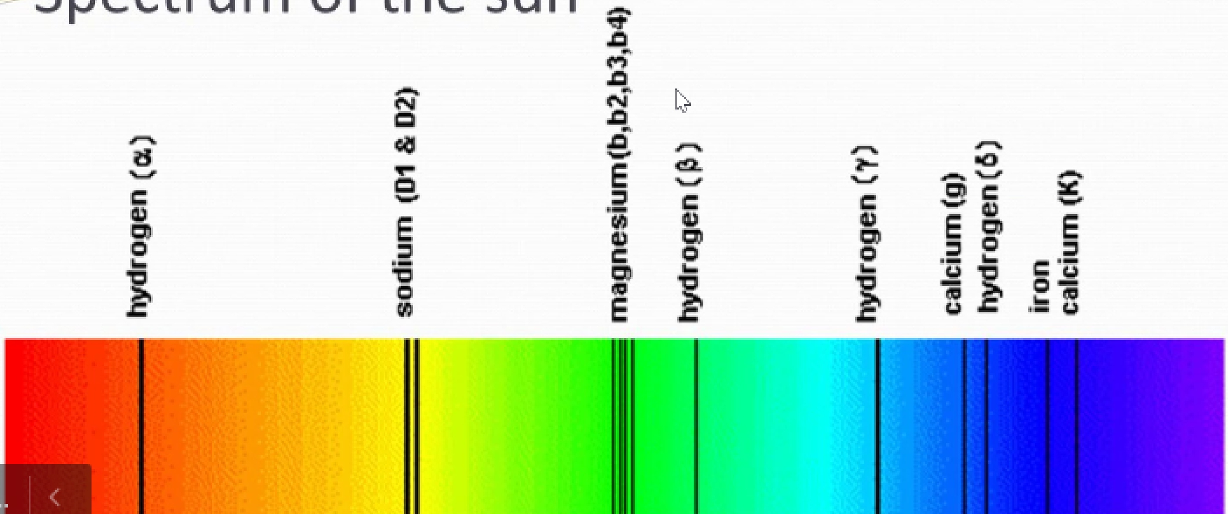
✓ Hottest: O stars; Coldest: M stars

✓ Each class divided into 10 sub-classes. For example, spectral class F includes F0, F1, .. F9.9; and then G0, ...

✓ Our Sun is a G2 star.

Hence, the absorption lines tell the chemical composition of the star concerned.

## Spectrum of the sun




The Harvard "computers" examining photographic plates

Catalogued roughly 5000 stars per month between 1911-1915

Made a major contribution to the system of stellar classification (O, B, A, F, G, K, M) in 1911-1915

Annie Jump Cannon (1863–1941)

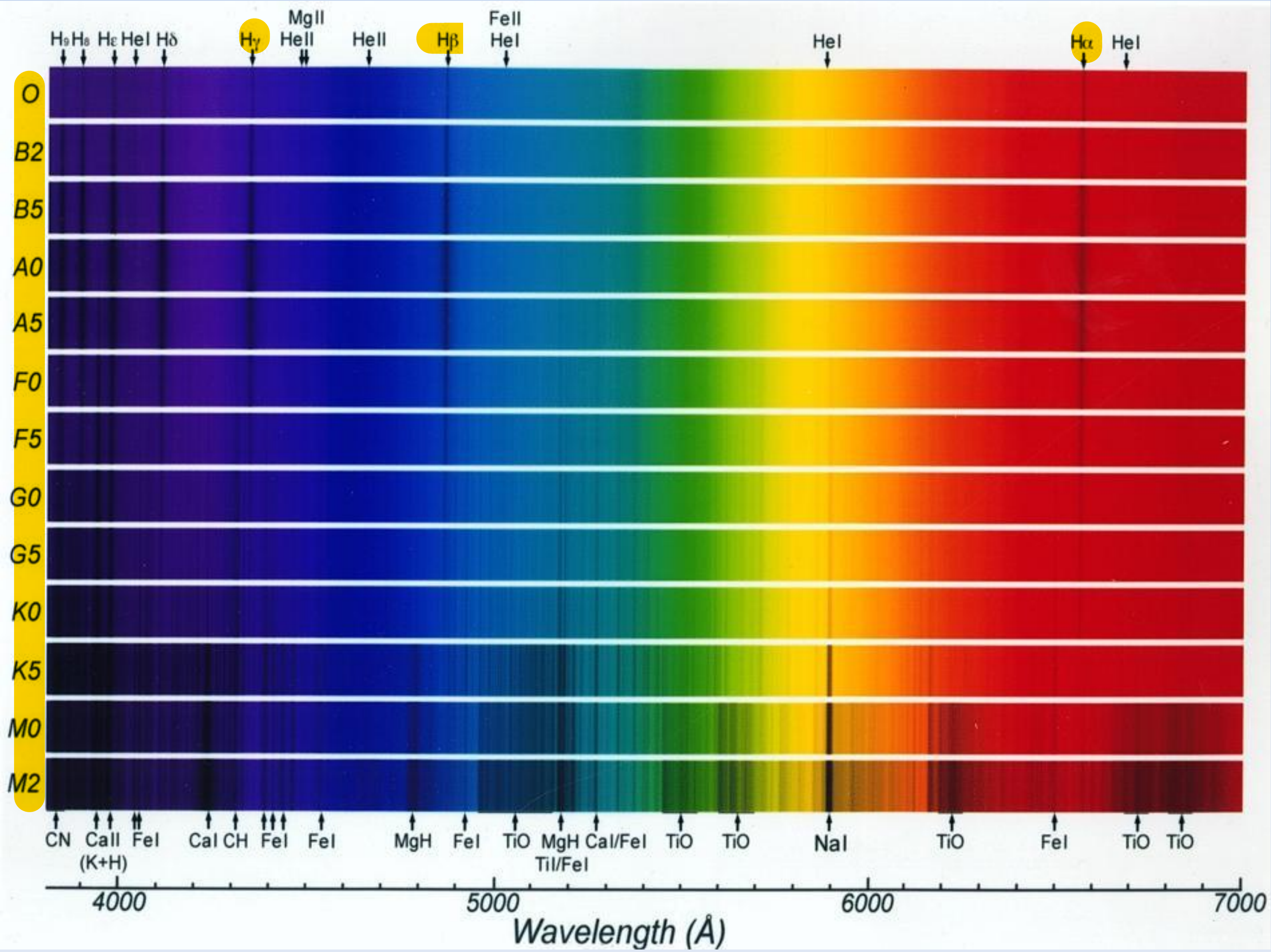
# 6.5 Physics of stellar spectra

| Spectral Class | Spectral Characteristics | Surface Temperature (K) |
|---|---|---|
| O | Hottest blue star with few lines. Strong He II absorption lines. | > 30,000 |
| B | Hot blue-white stars. He I absorption strongest at B2. HI (Balmer) absorption lines becoming stronger. | 20,000 |
| A | White stars. Balmer absorption lines strongest at A0. Ca II absorption lines becoming stronger. | 8,500 |
| F | Yellow-white stars. Ca II lines continue to strengthen as Balmer lines continue to weaken. | 6,500 |
| G | Yellow stars. Ca II lines continue becoming stronger. Fe I, other neutral lines becoming stronger. | 5,500 |
| K | Cool orange star. Ca II H and K lines strongest at K0, becoming weaker later. Spectra dominated by metal absorption lines. | 4,500 |
| M | Coolest red stars. Spectra dominated by molecular absorption bands, especially titanium oxide. Neutral metal absorption lines remain strong. | 3,000 |

# 6.5 Physics of stellar spectra

*Question:* Hydrogen is the most abundant elements in the universe. Why don't Balmer lines show up in all stars' spectra?

# 6.5 Physics of stellar spectra



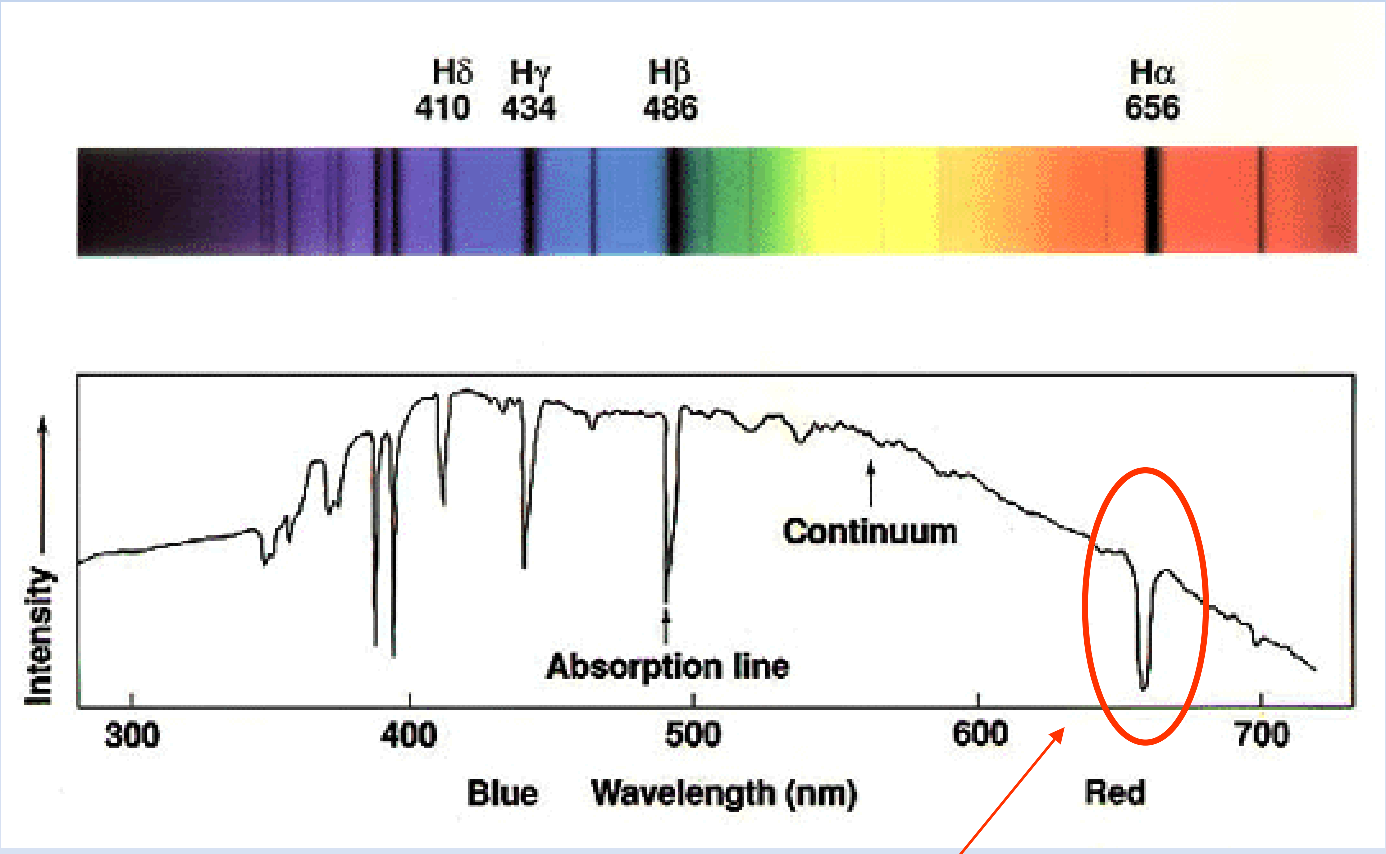
# 6.5 Physics of stellar spectra

- ✓Balmer lines come from electron transition between $N = 2$ and a higher energy shell
- ✓For a hot star, hydrogen atoms are ionized easily by high-energy radiation. When hydrogen's electron is torn away, no hydrogen spectral lines produced. Therefore, Balmer lines are relatively weak in a hot star
- ✓For a cold star, electron in the lowest orbit ($N = 1$), the corresponding transition cannot produce the Balmer series

# 6.5 Physics of stellar spectra

## Structure spectral lines

吸收的不是一条线，而是一个宽度

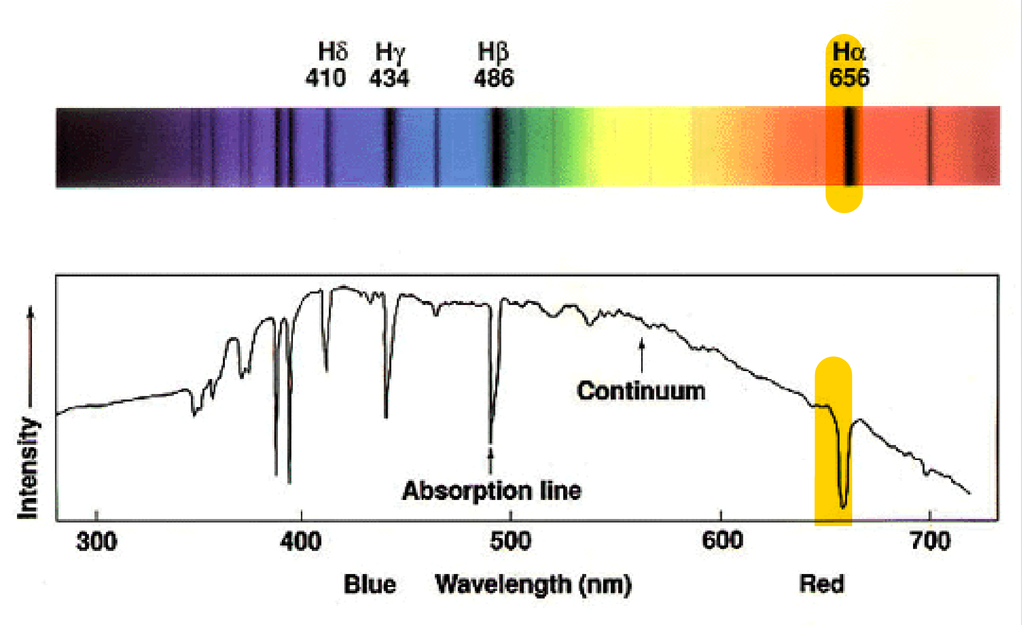



Detailed structure of a line called *Line profile*

# 6.5 Physics of stellar spectra

## Structure spectral lines

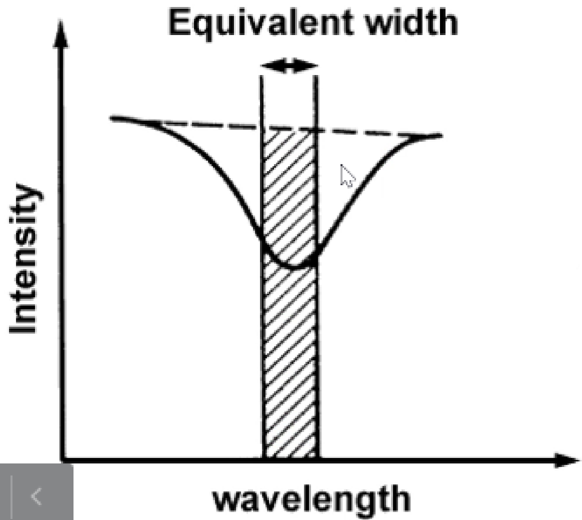
- ✓Area of the spectral line indicates how much energy is absorbed from continuum
- ✓proportional to amount of atoms in the star's atmosphere to absorb the photons
- ✓In a broad and deep spectral line more energy is being absorbed. There are hence more atoms.



# 6.5 Physics of stellar spectra

## Structure spectral lines

温度影响宽度，宽度用来估计星体H的数量




In practice, one calculate the equivalent width which is defined in a way to preserve the same area as the observed line:

- ✓ Indicate the strength of an absorption line;
- ✓ for easy comparison.

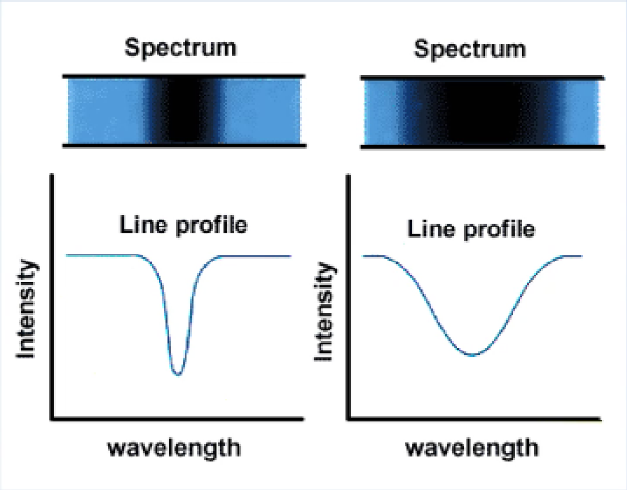
# Other factors determine the structure of spectral lines: Doppler broadening

- ✓ Also known as thermal broadening – broaden the spectral line due to random thermal motions of particles.
- ✓ Assume $v \ll c$, $\dfrac{\Delta\lambda}{\lambda} = \dfrac{v_r}{c}$
- ✓ By Maxwell distribution,

$$v_{\text{rms}} = \sqrt{3kT/m}$$

- ✓ width of spectral line:

$$\frac{\Delta\lambda}{\lambda} \approx \frac{2}{c}\sqrt{\frac{3kT}{m}}$$



# Other factors determine the structure of spectral lines: Doppler broadening

Exercise: Calculate the Doppler broadening of the $H_\alpha$ line of the Sun. Given that the surface temperature of the Sun is 5770 K, the frequency of $H_\alpha$ is $\lambda = 6563\,\text{Å}$, the mass of hydrogen atom is $m = 1.67 \times 10^{-27}$ kg, the Boltzmann constant is

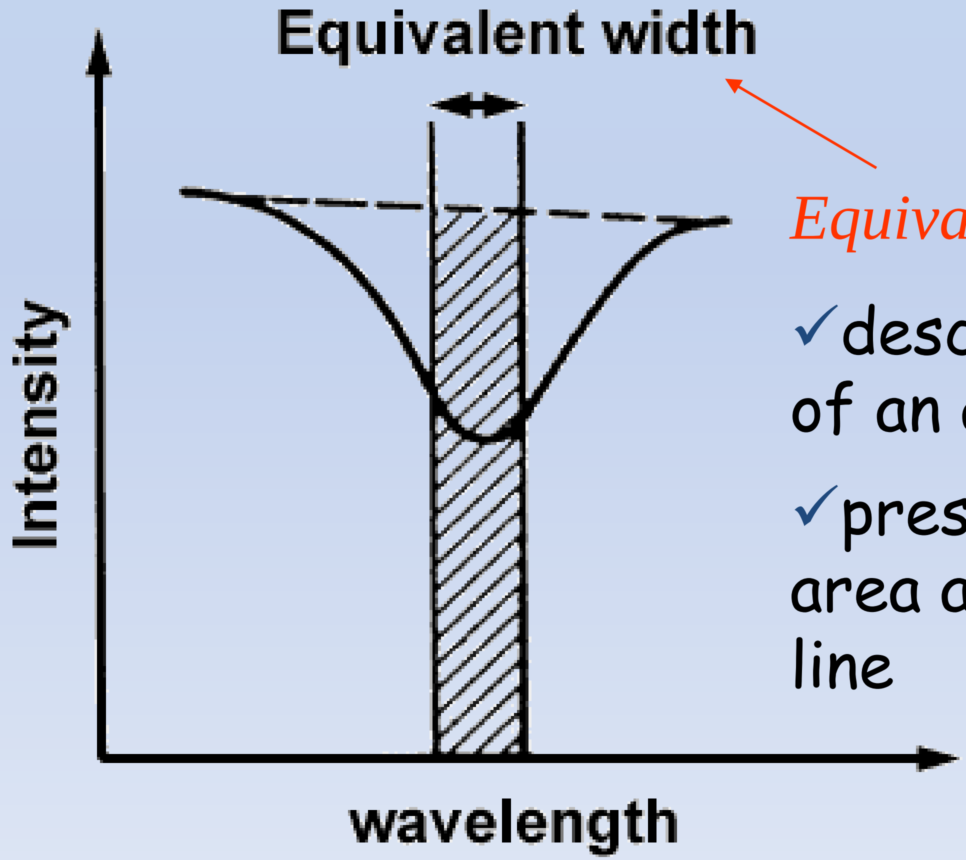
$$k = 1.380 \times 10^{-23}\ \text{J K}^{-1}$$

$$\text{Å} = 10^{-10}$$

$\Delta\lambda \approx 0.52$ Å

# 6.5 Physics of stellar spectra

## Structure spectral lines




*Equivalent width w*:

✓describe the strength of an absorption line

✓preserve the same area as the observed line

# 6.5 Physics of stellar spectra

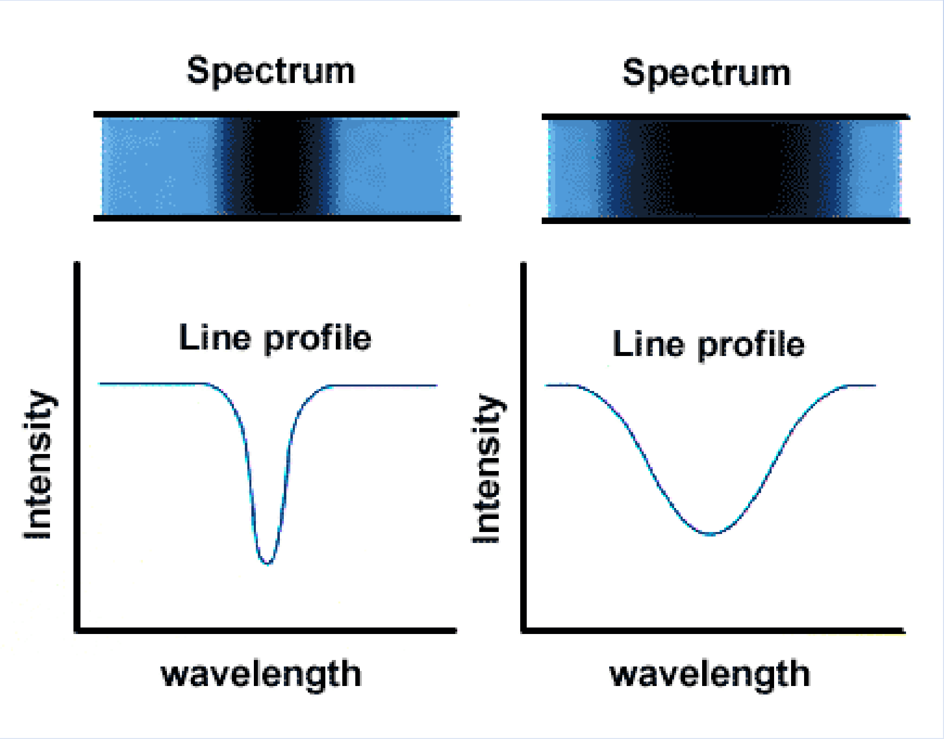
## Structure spectral lines

- ✓ Doppler broadening – broaden the spectral line due to random thermal motions of particles.
- ✓ Assume $v << c$, $\frac{\Delta\lambda}{\lambda} = \frac{v_r}{c}$
- ✓ By Maxwell distribution,

$$v_{\text{rms}} = \sqrt{3kT/m}$$

- ✓ width of spectral line:

$$\frac{\Delta\lambda}{\lambda} \approx \frac{2}{c}\sqrt{\frac{3kT}{m}}$$



# 6.5 Physics of stellar spectra

## Structure spectral lines

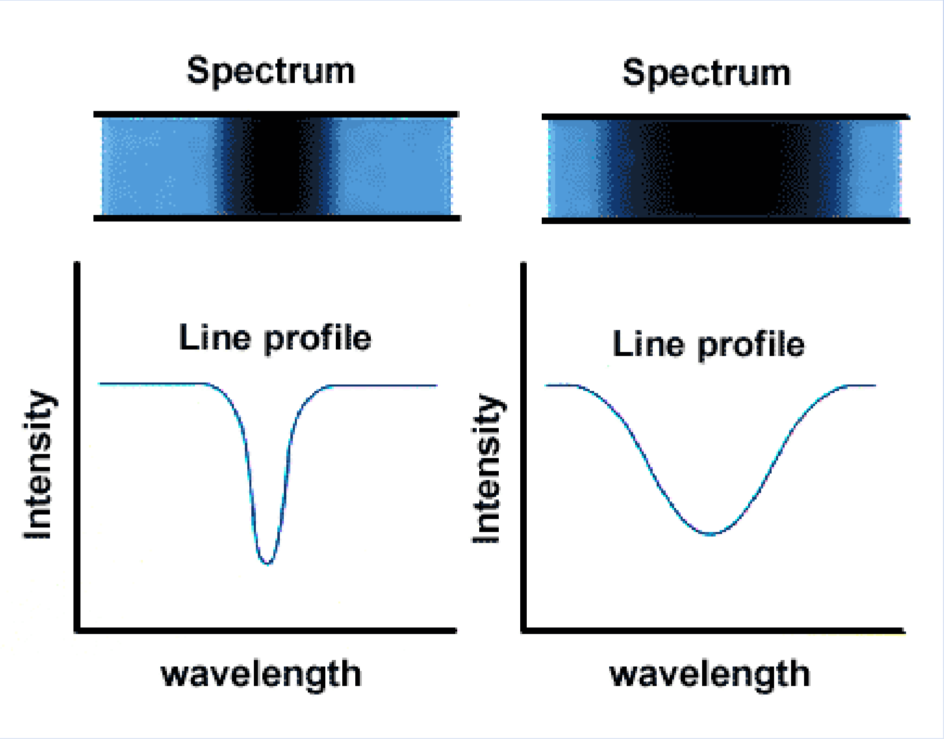
- For example, $\mathrm{H}_\alpha$ line of the Sun

$$T = 5770\,\mathrm{K},\quad m = 1.67\times10^{-27}\,\mathrm{kg},\;\; \lambda = 6563\,\overset{\circ}{\mathrm{A}},$$

$$k = 1.380\times10^{-23}\,\mathrm{J\,K^{-1}}$$

$$\Delta\lambda \approx 0.52\,\overset{\circ}{\mathrm{A}}$$

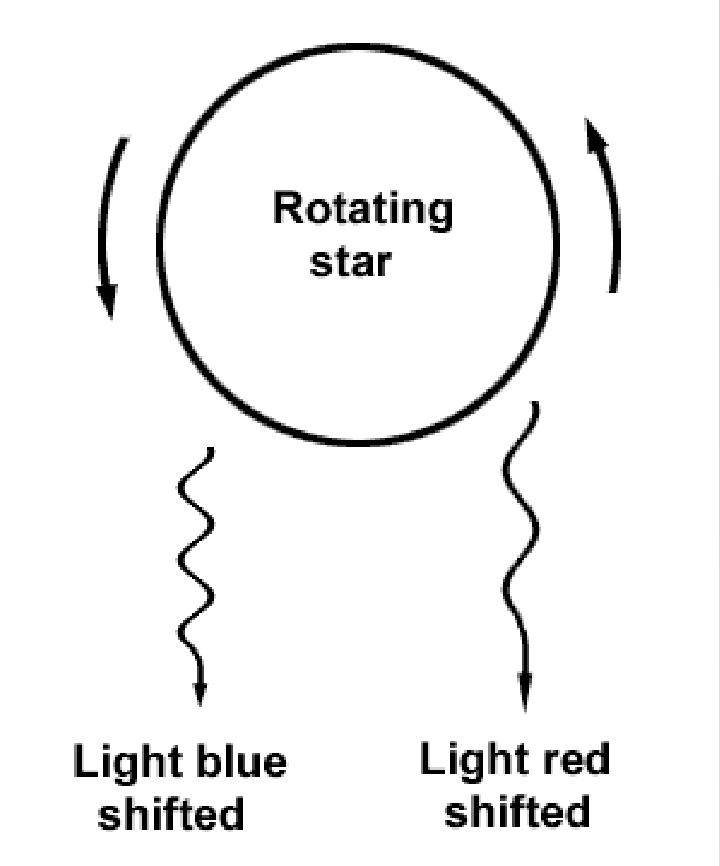
- 1000 times > *natural broadening* (from the uncertainty principle)



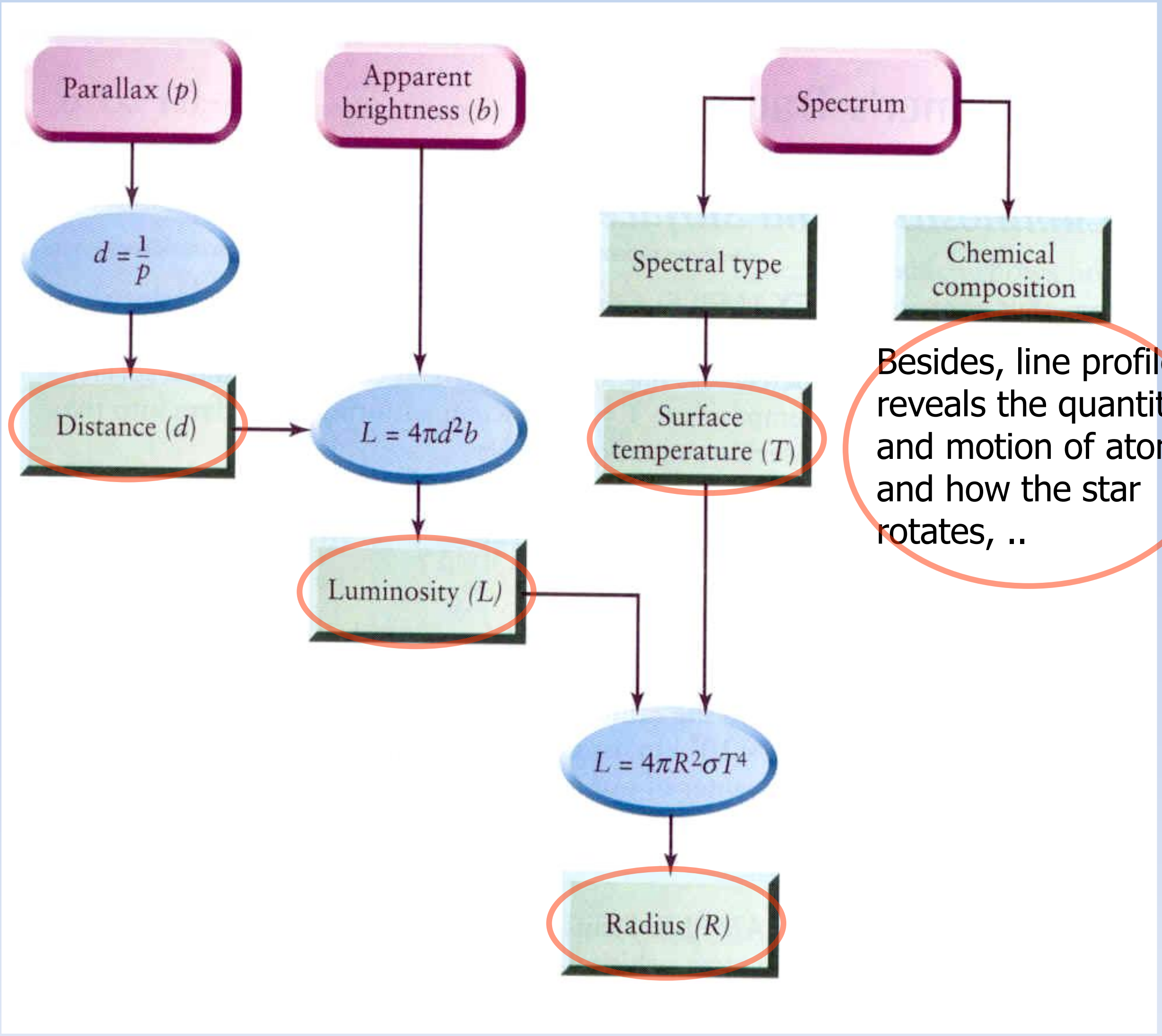
# 6.5 Physics of stellar spectra

## Structure spectral lines

- ✓ Rotational broadening - light coming from a rotating star is Doppler shifted
- ✓ Astronomers deduce how fast the star is spinning



# 6.5 Physics of stellar spectra

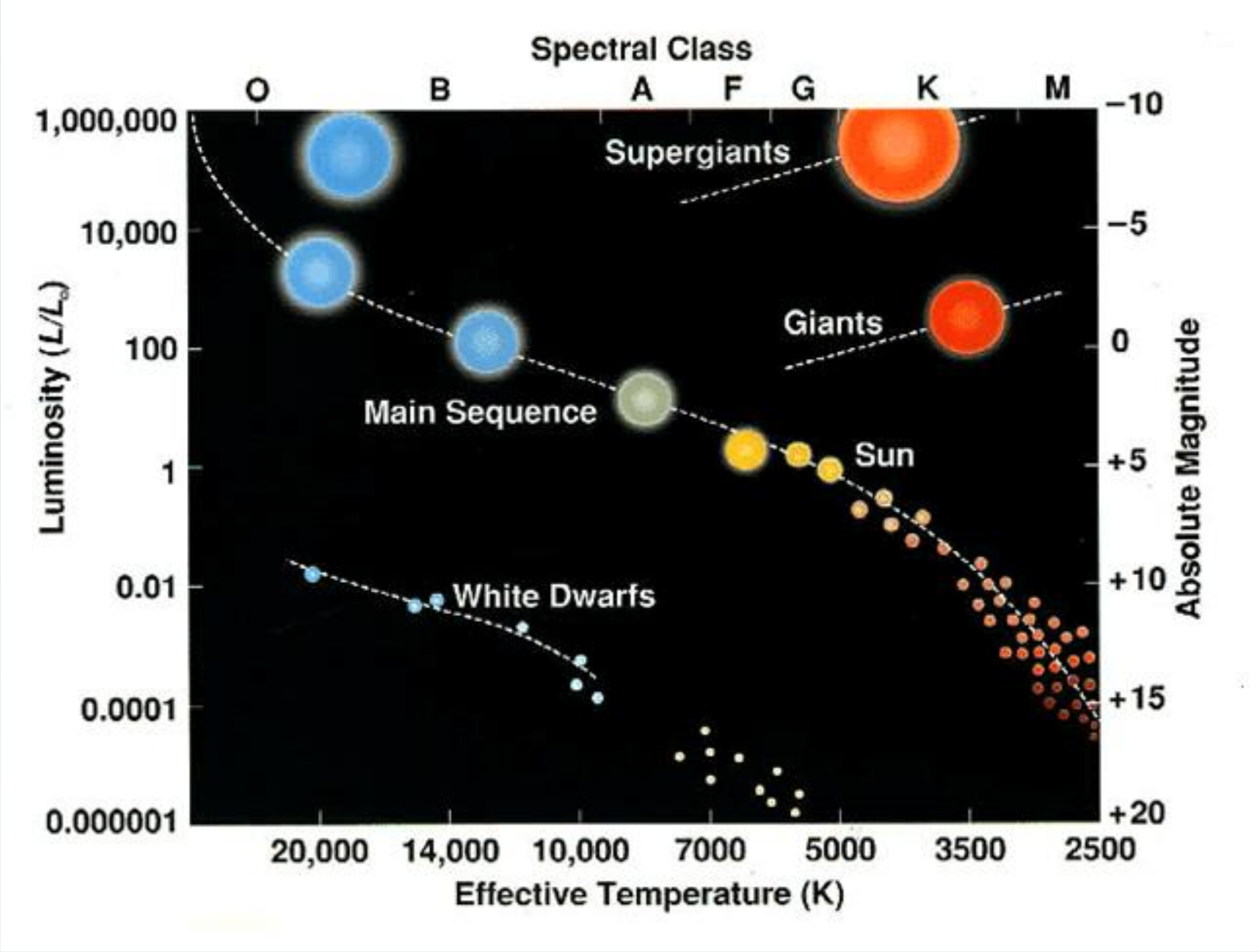



Besides, line profile reveals the quantity and motion of atoms, and how the star rotates, ..

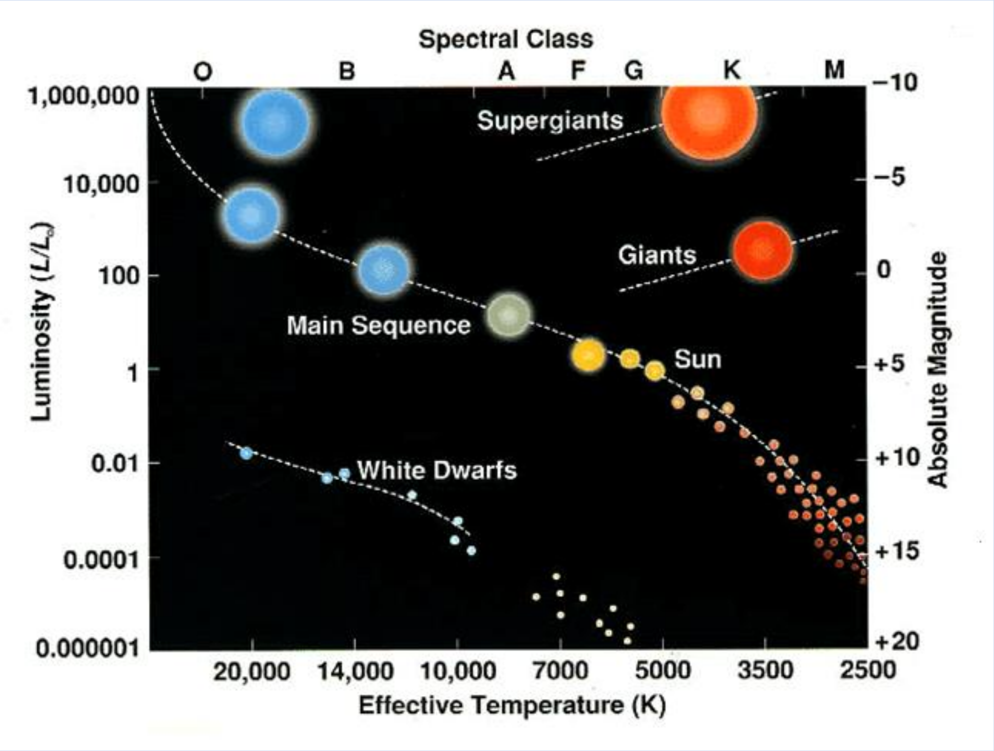
# 6.6 Hertzsprung-Russell (H-R) diagram

*Luminosity* vs *spectral classes* (surface temperature)

和太阳相比的
相对亮度



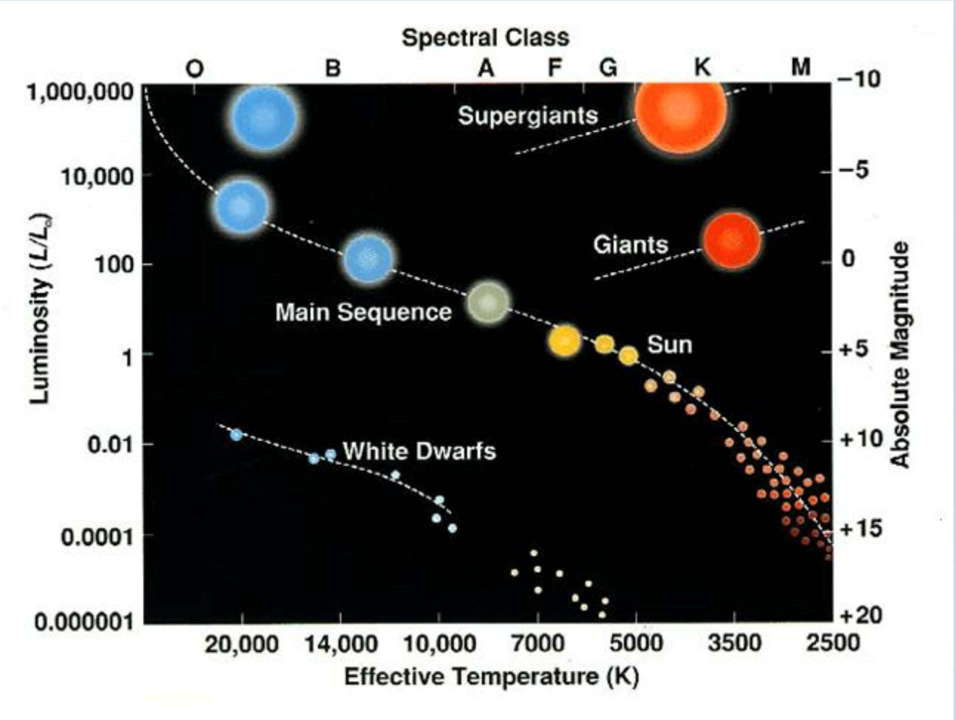
# 6.6 Hertzsprung-Russell (H-R) diagram




- ✓ Top: luminous stars; bottom: faint stars
- ✓ left: hot stars; right: cold stars
- ✓ As star evolves, temperature and luminosity changes, so its position on the H-R diagram also changes.

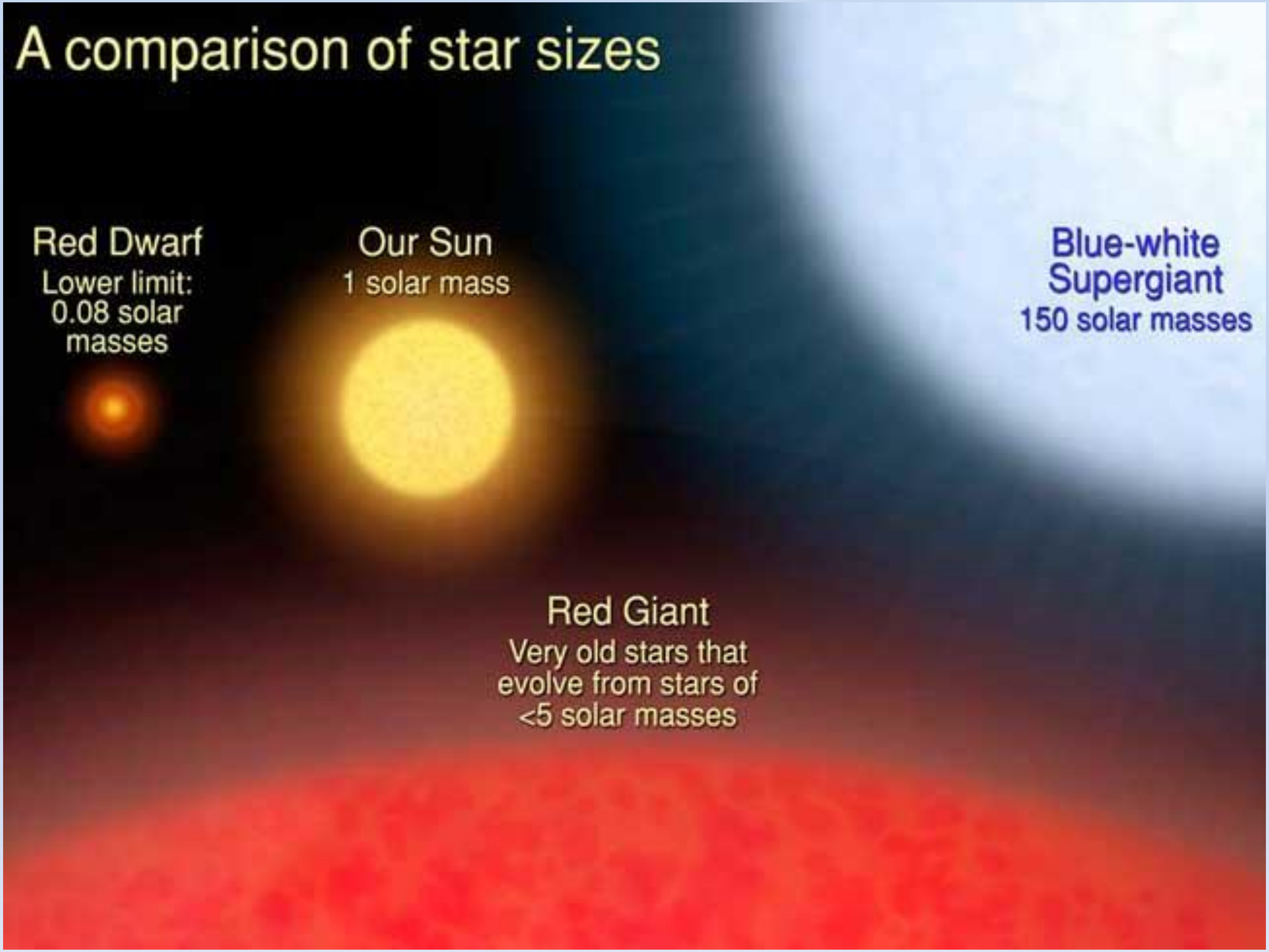
# 6.6 Hertzsprung-Russell (H-R) diagram

- ✓ *Main sequence*: A belt from upper left to lower right, 90% of all stars.
- ✓ cool stars are faint and small; hot stars are bright and large.




How large?

Credit: NASA, ESA, A. Field (STScl)

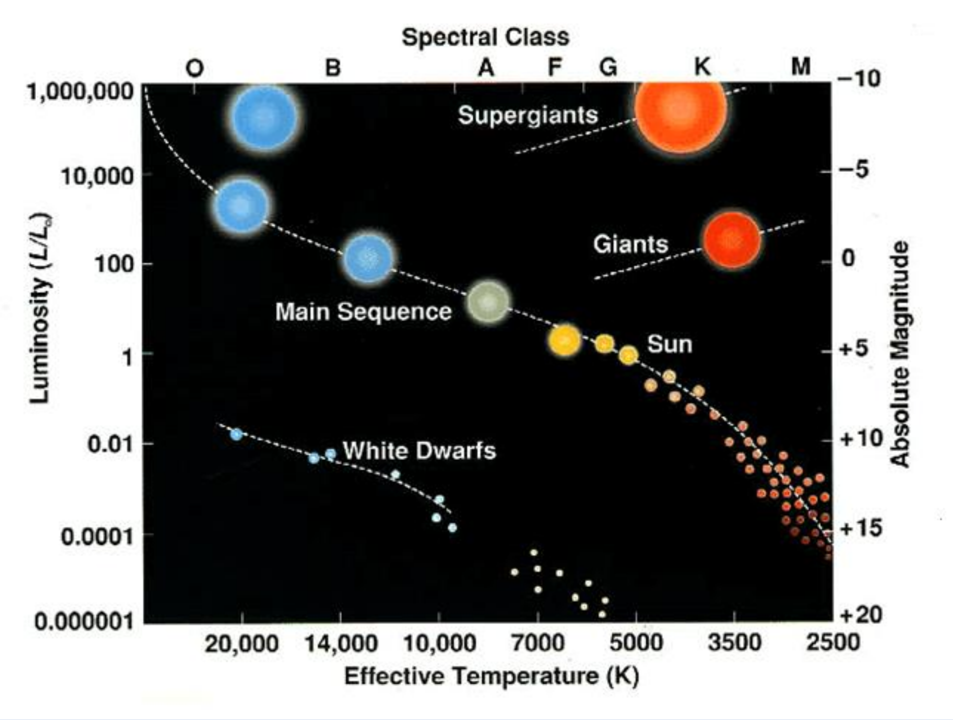



The stars on the H-R diagram have vastly different masses and sizes.

# 6.6 Hertzsprung-Russell (H-R) diagram

- ✓ *Giants* at the upper right corner, they are cool but luminous
- ✓ must have large surface area $R/R_{\odot}$ ~10-100
- ✓ *Supergiants* are even larger: $R/R_{\odot}$ ~100-1000

和太阳的比例



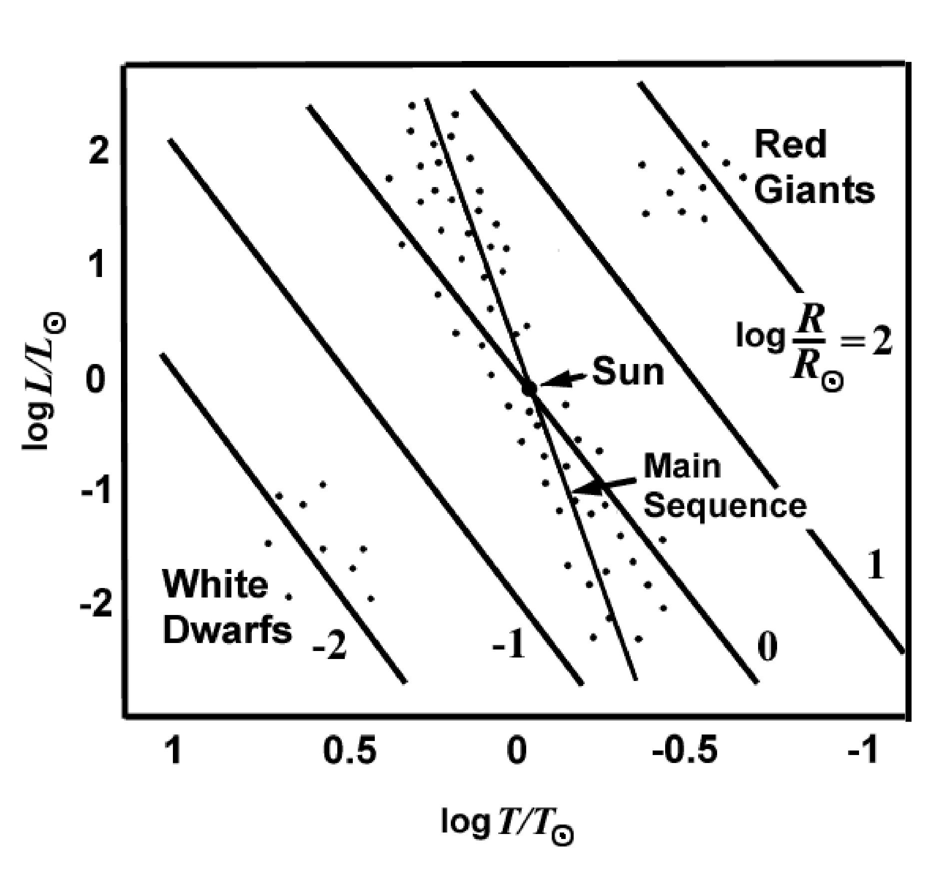
# 6.6 Hertzsprung-Russell (H-R) diagram

- ✓ Stefan-Boltzmann's law

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

$$\frac{L}{L_\odot} = \frac{R^2 T^4}{R_\odot^2 T_\odot^4}$$

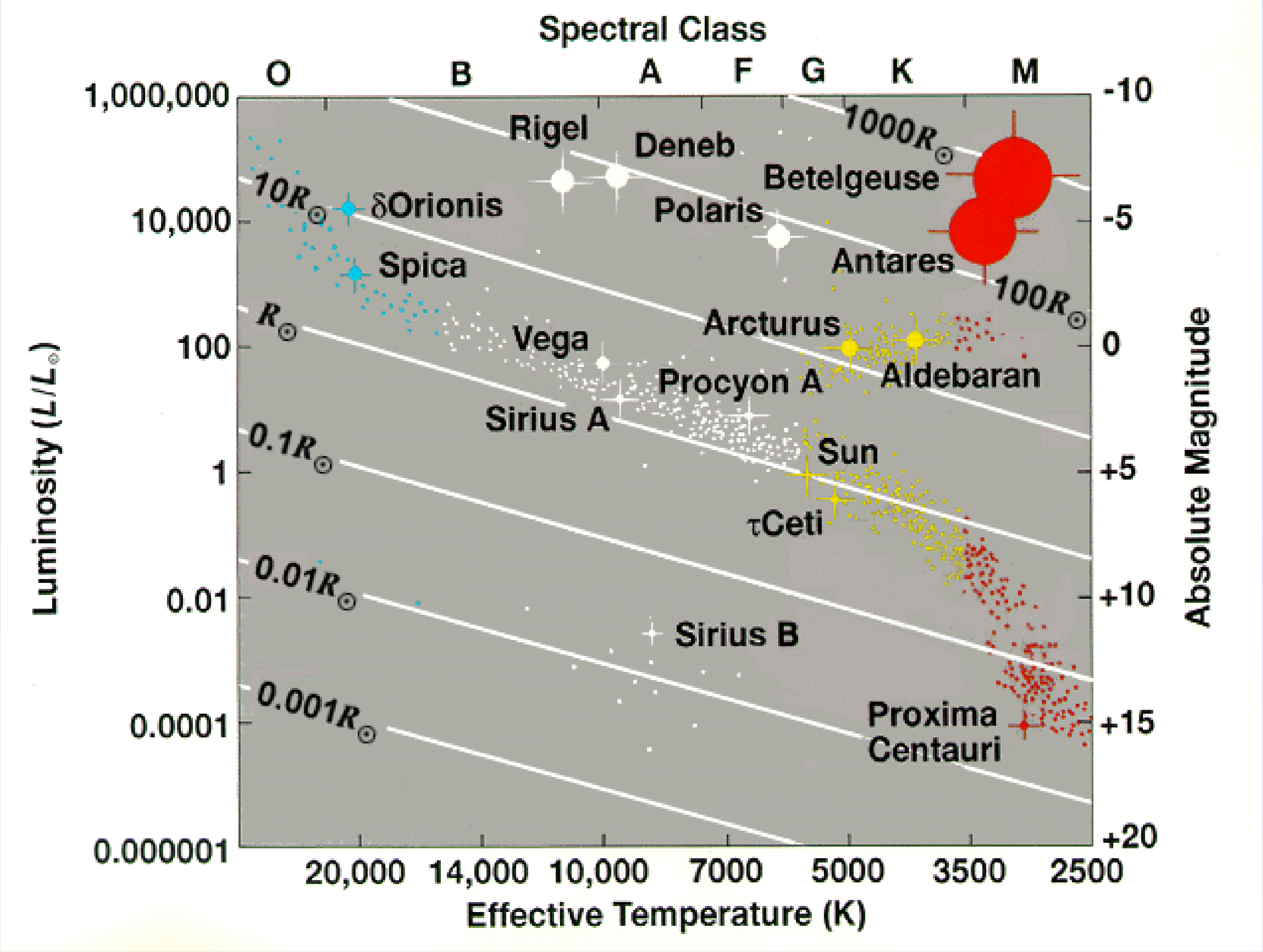
$$\log\left(\frac{L}{L_\odot}\right) = 4\log\left(\frac{T}{T_\odot}\right) + 2\log\left(\frac{R}{R_\odot}\right)$$




- ✓ Lines of constant radius

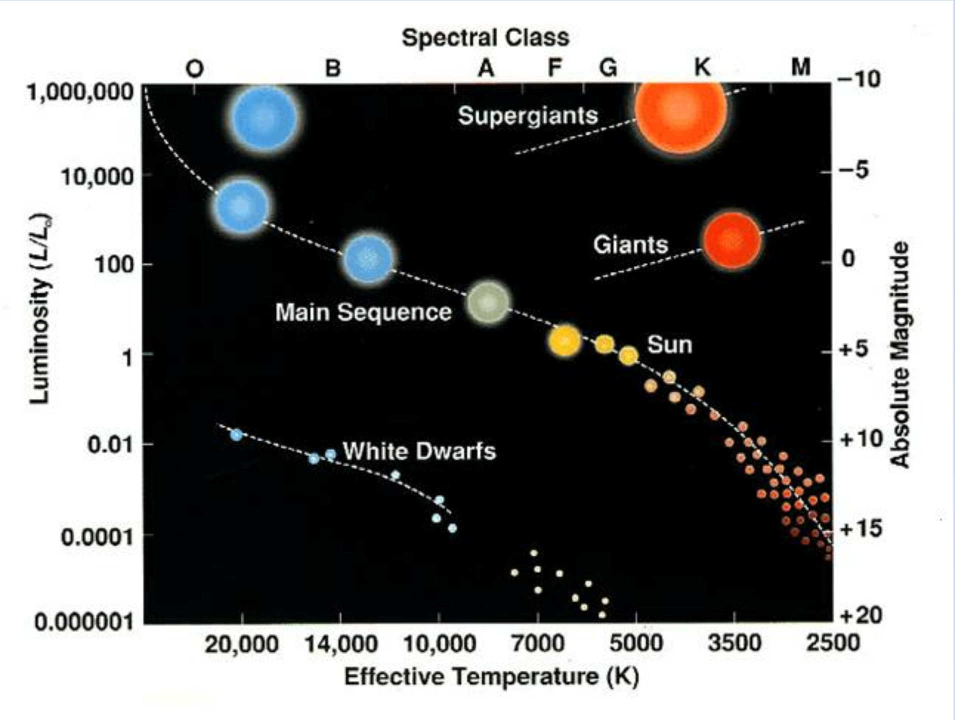
$$c = 2\log\left(\frac{R}{R_\odot}\right)$$

# 6.6 Hertzsprung-Russell (H-R) diagram

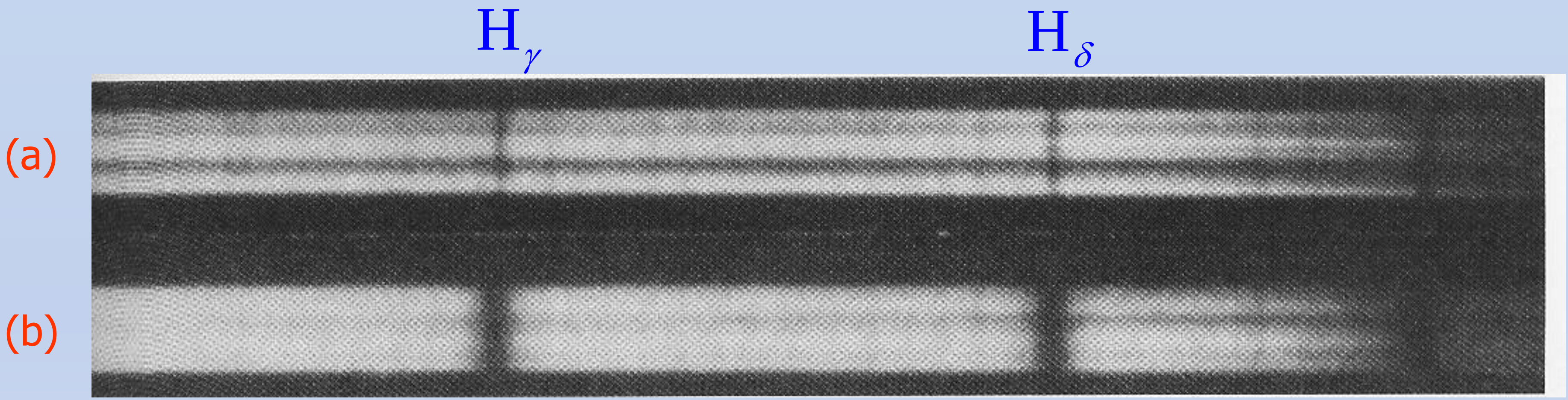


# 6.6 Hertzsprung-Russell (H-R) diagram

- ✓ *White dwarfs* lie in the lower left, they are hot but faint
- ✓ must be very small (~ size of Earth)



Turns out, there is degeneracy in our definition…




(a) B8 supergiant Rigel with $L = 100{,}000 L_\odot$ , one of the brightest stars in Orion

(b) B8 main-sequence star Algol with $L = 100 L_\odot$ , the second brightest star in Perseus

# 6.6 Hertzsprung-Russell (H-R) diagram

✓ *Luminosity classes* classify the stars according to their luminosity (practically the difference in spectral lines)

Ia *Bright supergiant*

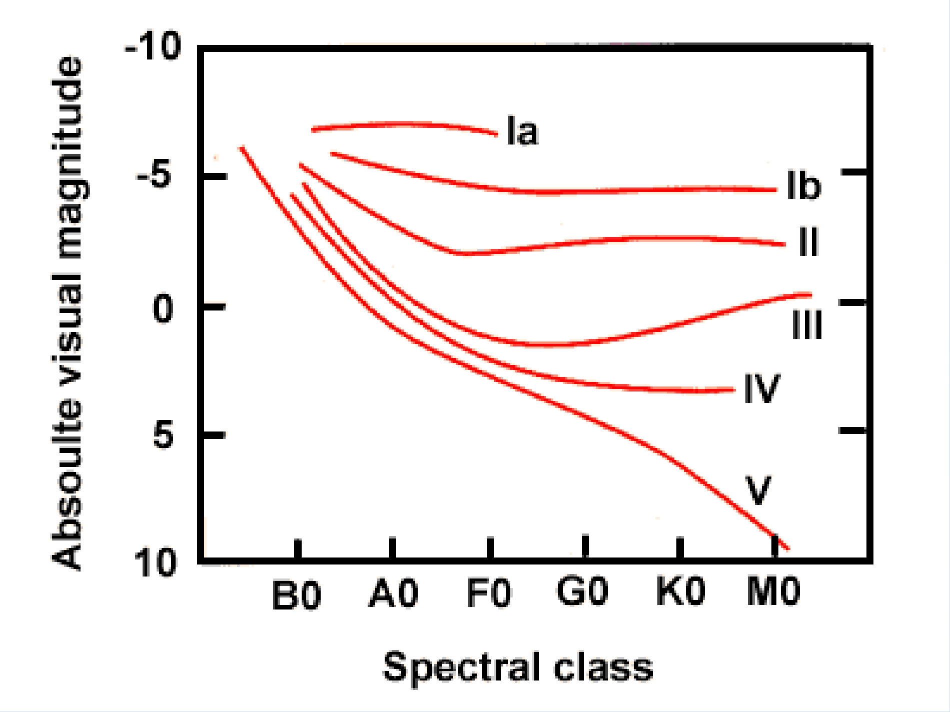
Ib *Supergiant*

II *Bright giant*

III *Giant*

IV *Subgiant*

V *Main-sequence star*

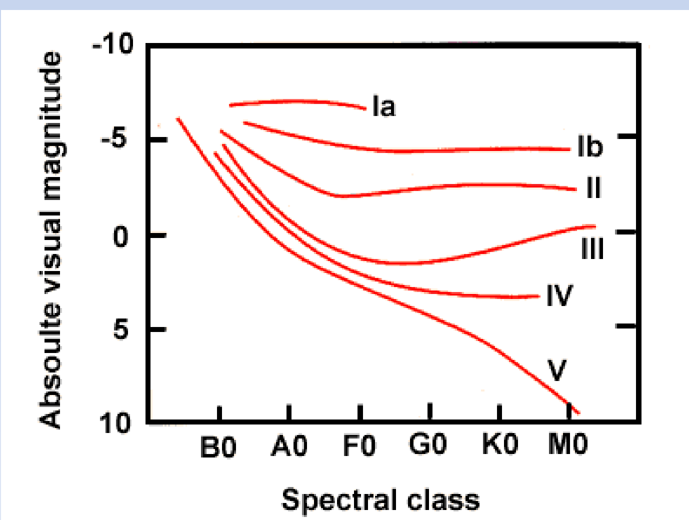


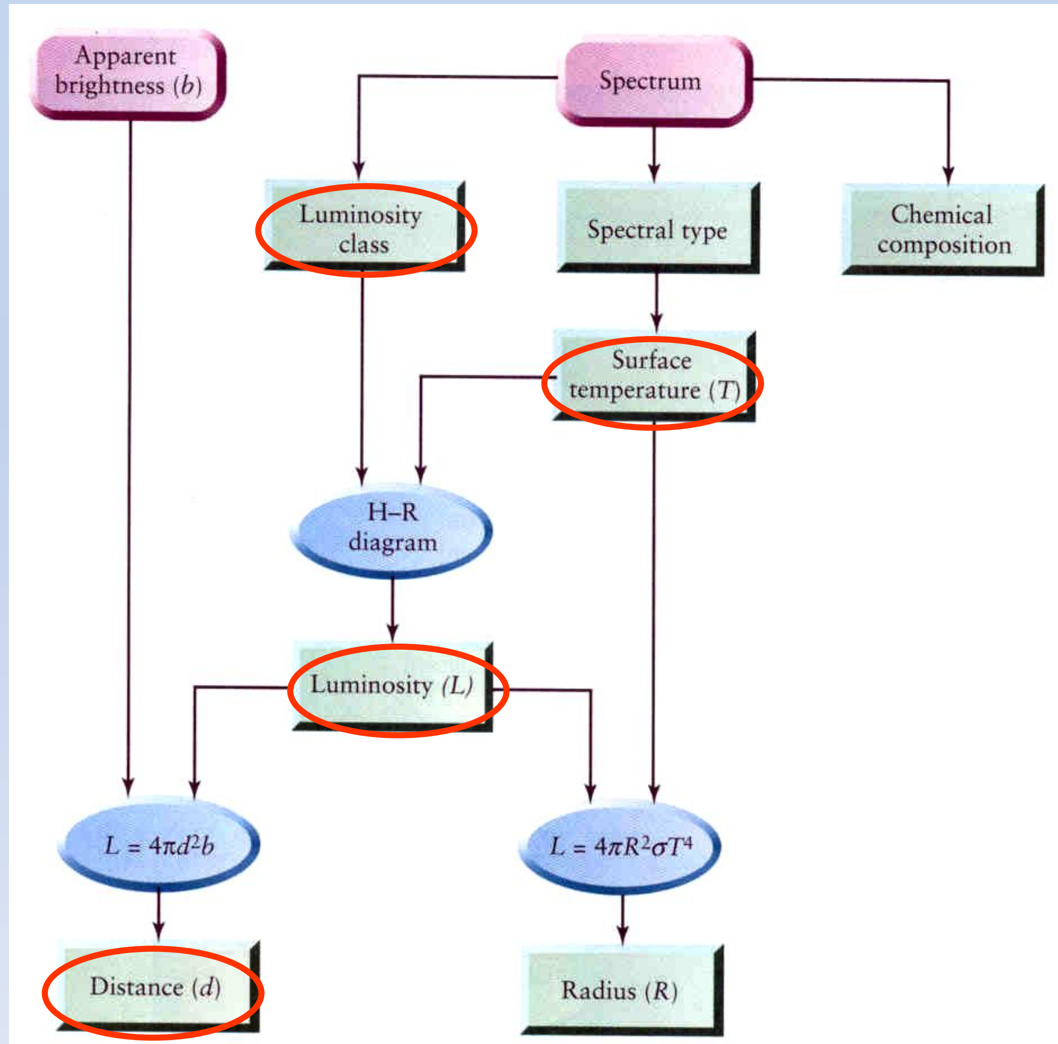
# 6.6 Hertzsprung-Russell (H-R) diagram

*Question:* How to determine the distance of a distant star from us?

# 6.6 Hertzsprung-Russell (H-R) diagram

Method of spectroscopic parallax



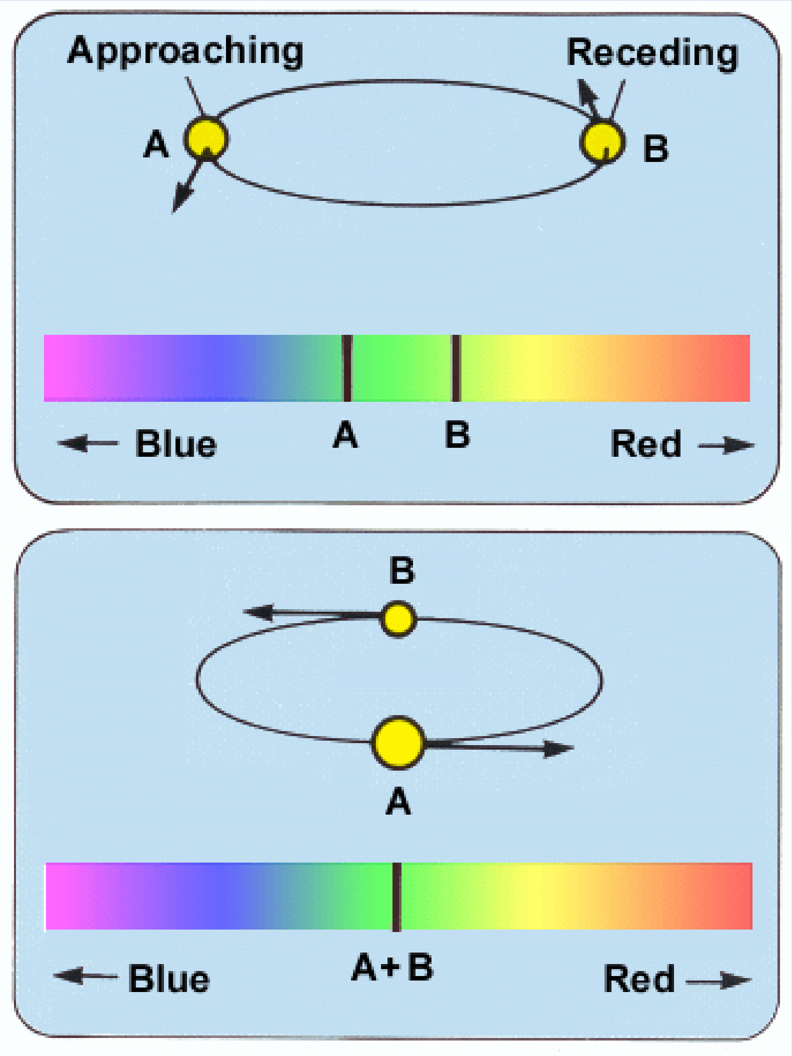

用来测很远的星体

# 6.7 Binary systems

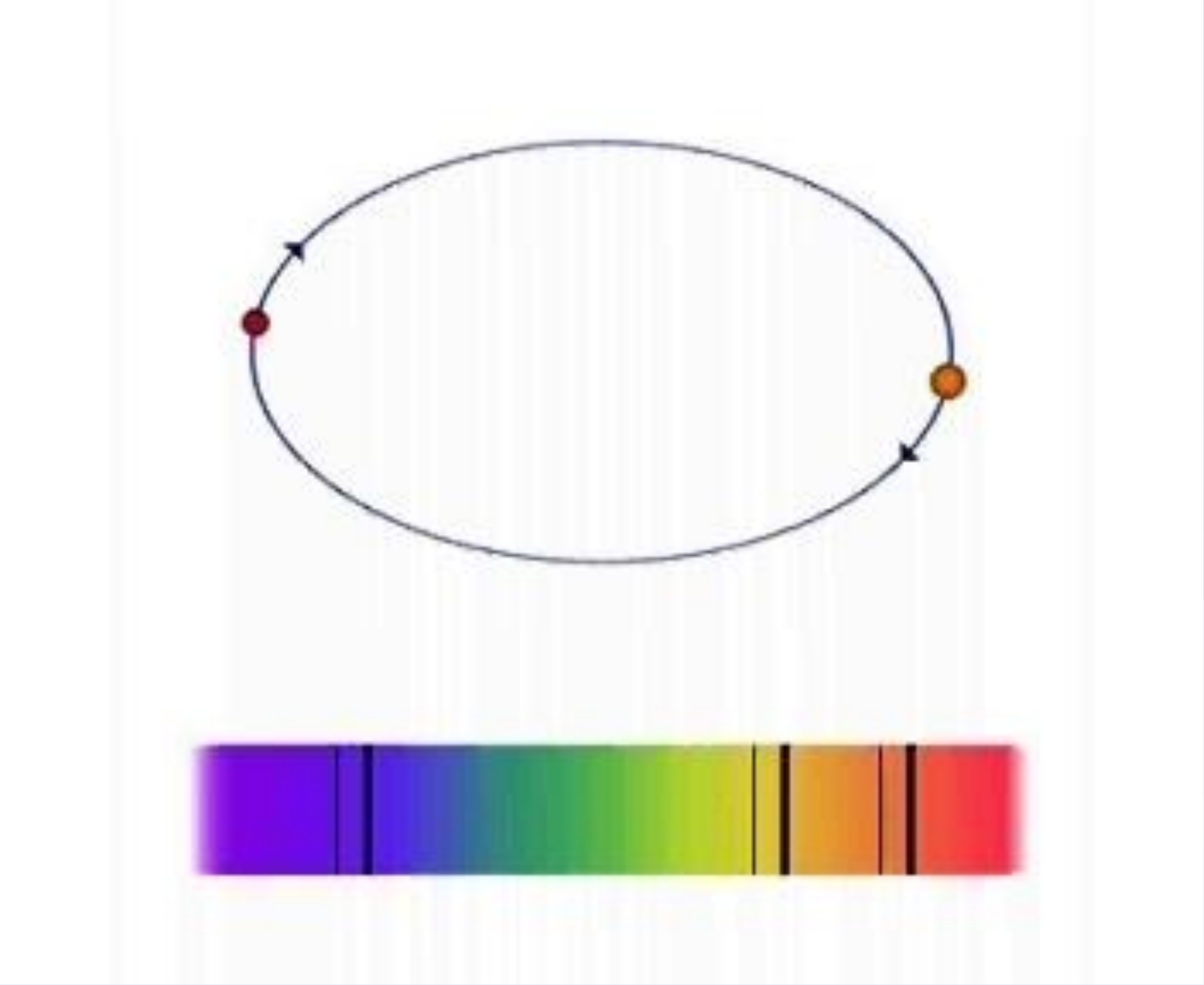
- ✓ A pair of stars appears at nearby the same position is called *double stars*
- ✓ *Optical double stars*: lie along nearly the same line of sight but are actually at very different distances from us
- ✓ Pairs of stars actually orbiting each other – *binary stars*, or *binaries*

# 6.7 Binary systems

- ✓ *Visual binaries*: Double stars gravitationally connected, can be resolved by optical telescopes
- ✓ *Spectroscopic binaries*: Gravitationally connected binaries too close to be resolved by optical telescopes, but spectra show periodic Doppler shifts



# 6.7 Binary systems

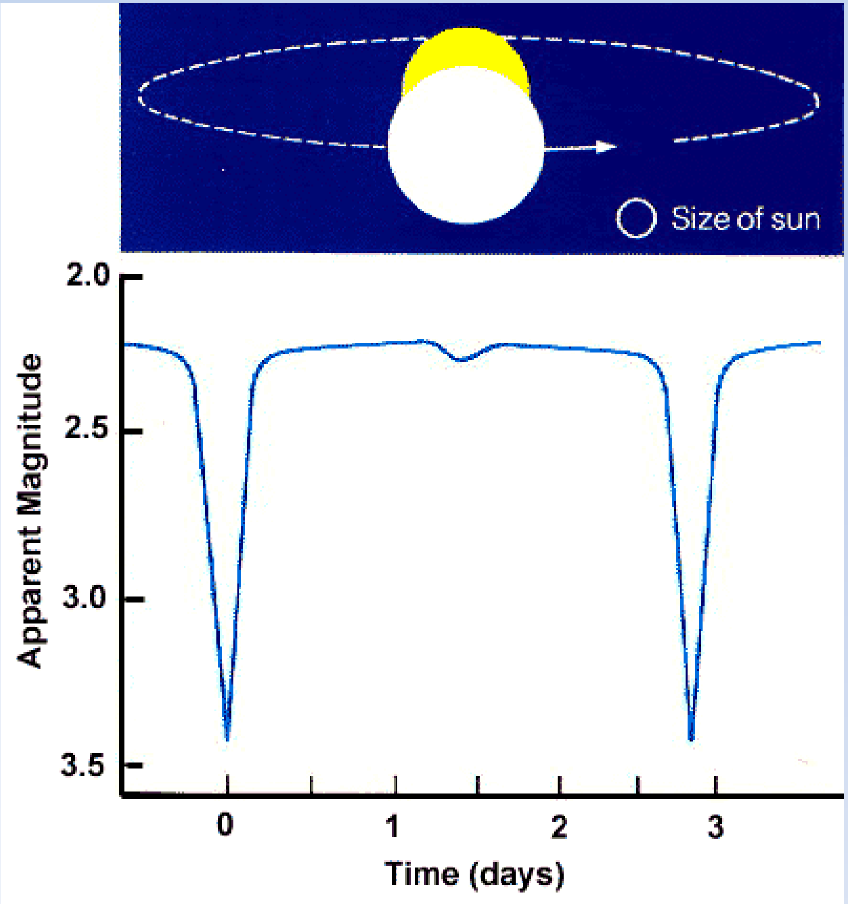


SpecBin.avi

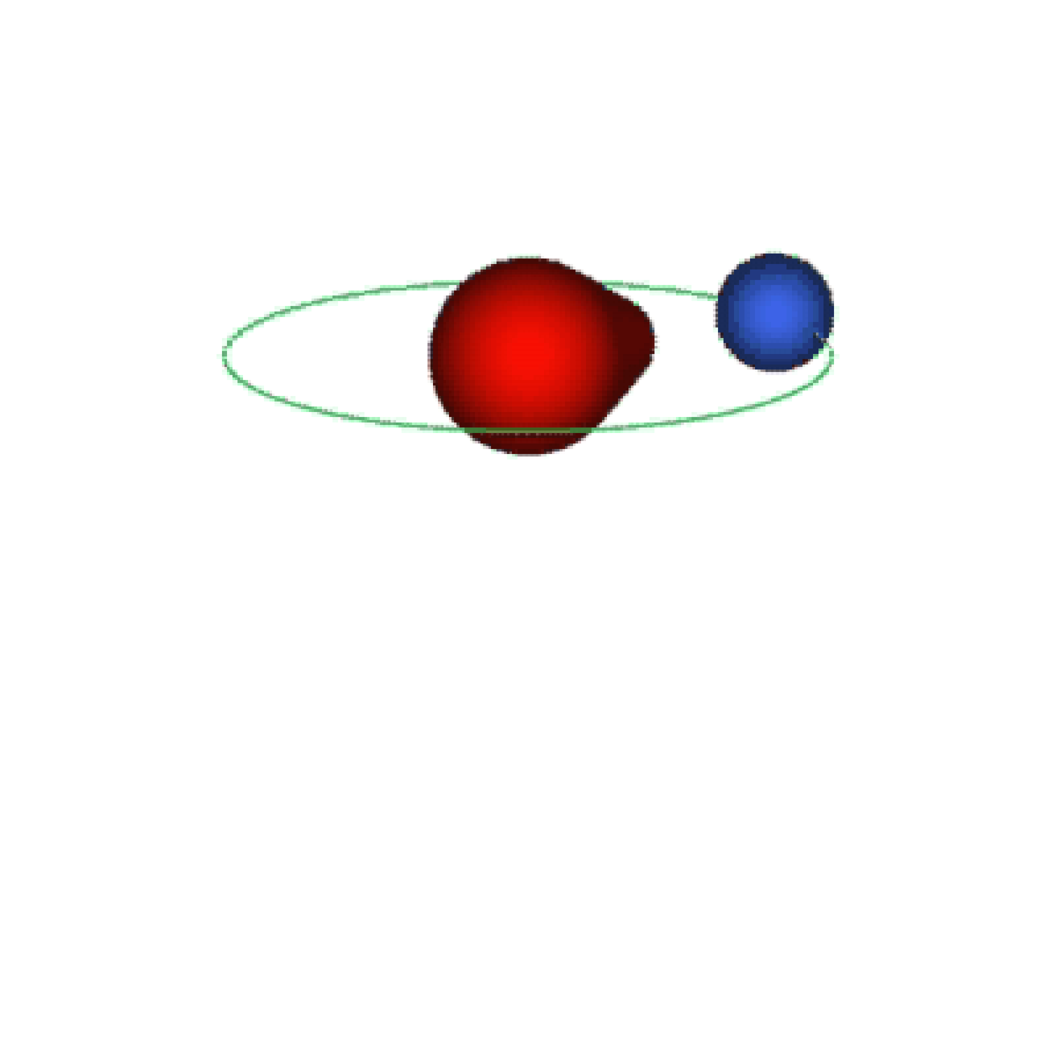
# 6.7 Binary systems

## Eclipsing Binaries

- ✓ Most binary stars are too close to be resolved by optical telescopes,
- ✓ but may show periodic variation in brightness by eclipses



# 6.7 Binary systems



EclBinary2.mpg

# 6.7 Binary systems

## Eclipsing Binaries

- ✓ Analysis of light curves allows one to determine the ratio of luminosity and radii of the component stars