STELLAR PROPERTIES

PHY-HE-6046

Astronomy and Astrophysics

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🟥 Fundamental Properties

● Observable Properties

Temperature

Chemical composition

Radius

Mass

Apparent Brightness

Luminosity

Distance

FIRST STEP IS MEASURING THE **DISTANCE, BRIGHTNESS** AND **LUMINOSITY** OF STARS

DISTANCE

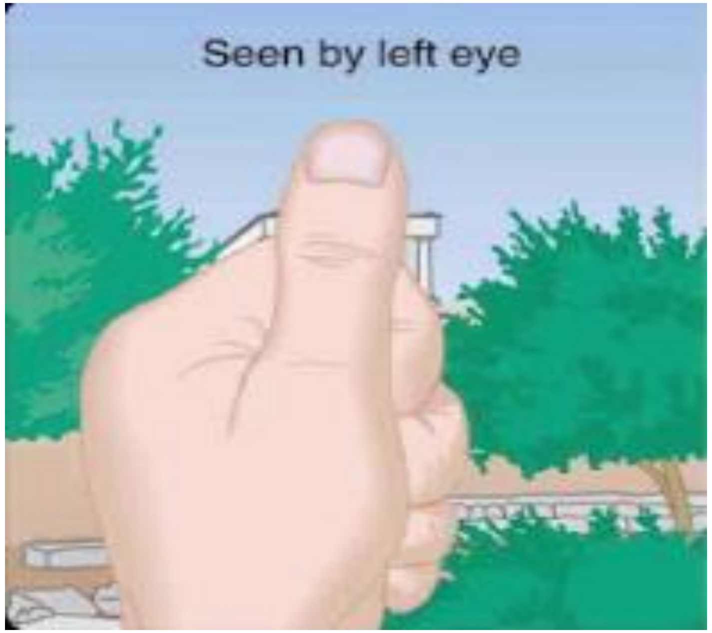
- One of the most basic thing we can measure-still one of the most important and difficult task

How to determine distance(d)?

One method: Stellar Trigonometric parallax

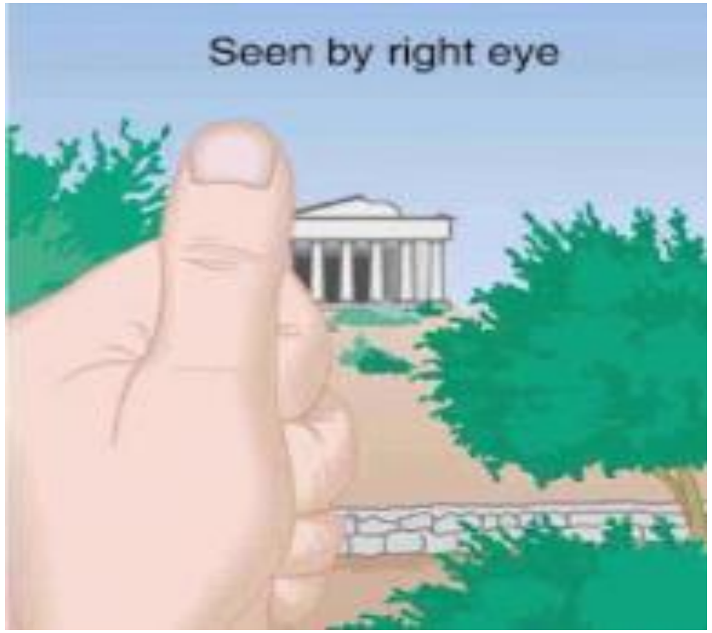
TRIGONOMETRIC PARALLAX METHOD

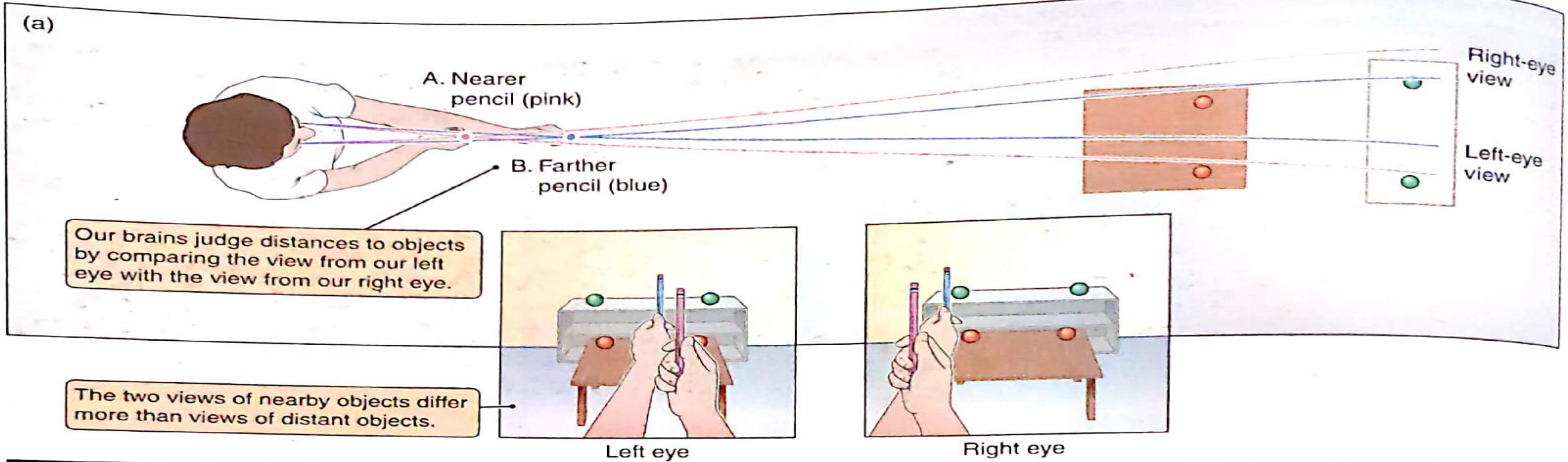
To determine distance of a star



PARALLAX:

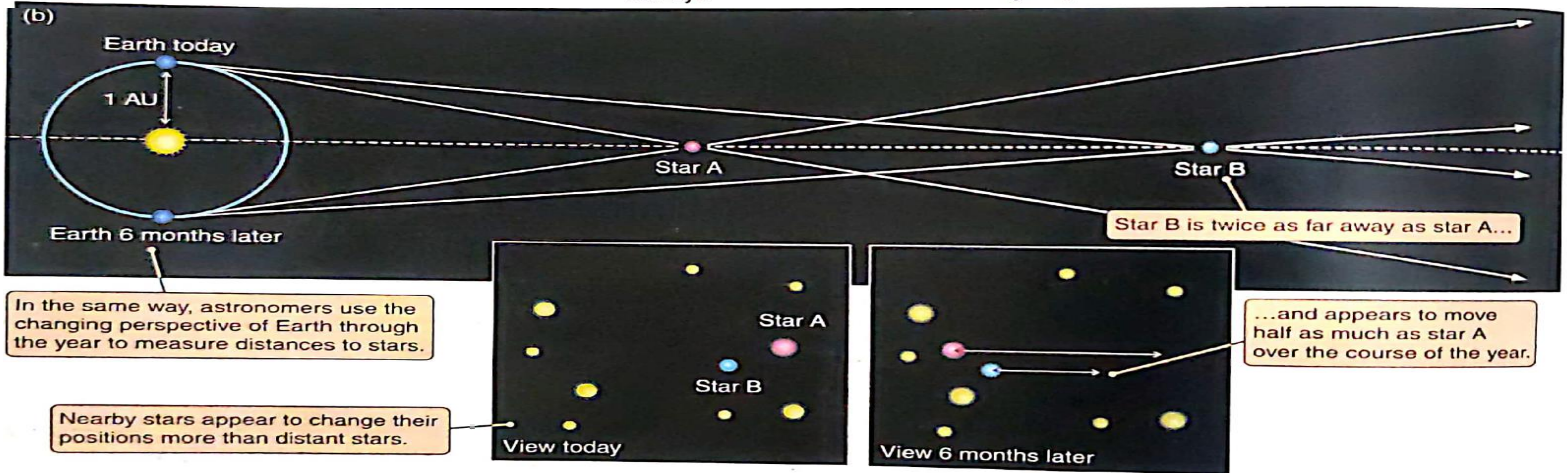
The apparent change in position observed when the star is sighted from opposite locations of the Earth's orbit around the Sun.





Our brains judge distances to objects by comparing the view from our left eye with the view from our right eye.

The two views of nearby objects differ more than views of distant objects.



Star B is twice as far away as star A...

...and appears to move half as much as star A over the course of the year.

In the same way, astronomers use the changing perspective of Earth through the year to measure distances to stars.

Nearby stars appear to change their positions more than distant stars.

MEASURING PARALLAX

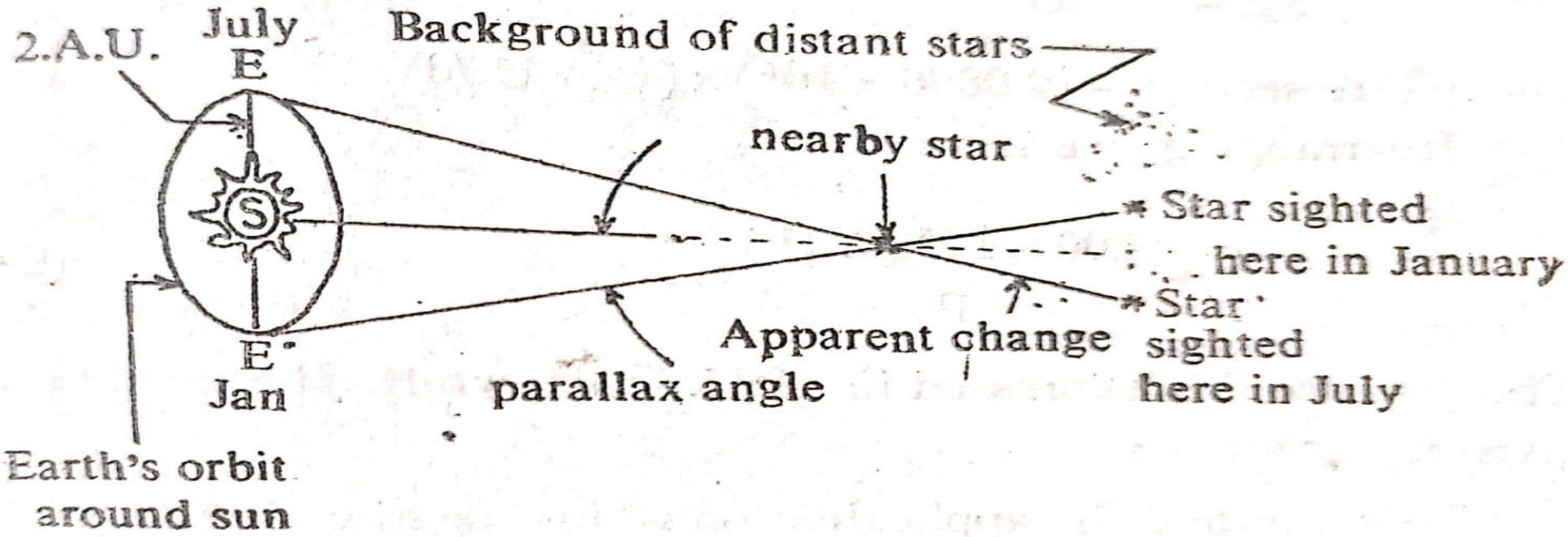
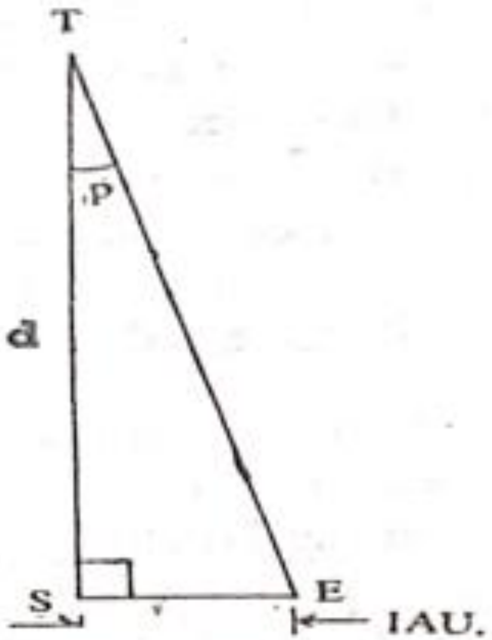


Fig. 2.1. Trigonometric parallax method for measuring distance to nearby stars.



The triangle showing the parallax angle p, the distance of the star to the Sun.
SE = 1 A U

$$\tan p = \frac{1\,A.U.}{d}$$

$$p(in\ radian) = \frac{1\,A.U.}{d}$$

$$p(in\ arc\ second) = 2.06 \times 10^5 \left(\frac{1\,A.U.}{d}\right)$$

1 radian = 206264.81’’

$$\mathrm{d} = \left(\frac{2.06\times 10^5\,A.U.}{p}\right)$$

Definition of parsec: Put **p = 1’’**

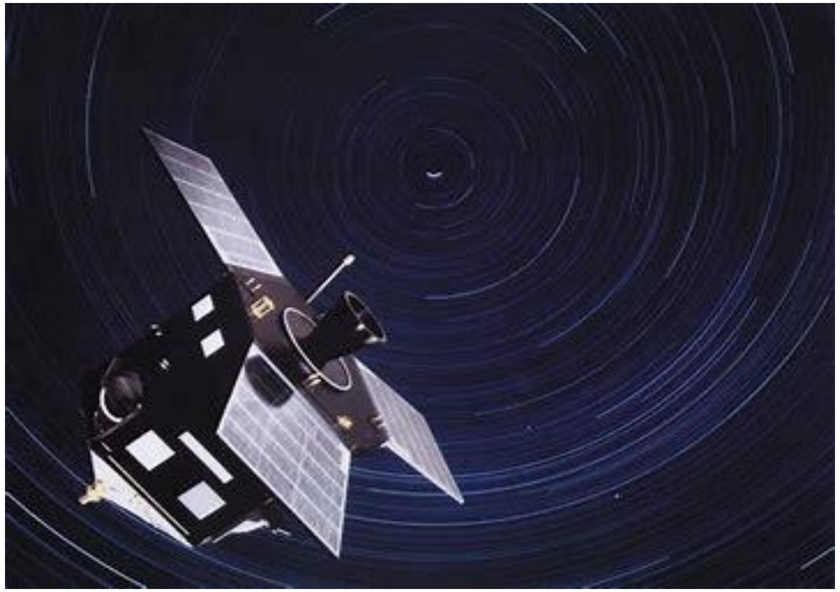
It is the distance to a star that makes a parallax angle of 1 arcsec

$d = 2.06 \times 10^5 \times 1.49 \times 10^{11}$ m = 3.0694×10^{16} m

1 parsec= 3.26 light years = $3.26 \times 9.46 \times 10^{15}$ m = 3.083×10^{16} m

- 1st successful measurement----- F.W.Bessel in 1838
- Parallax of .314’’ for the star 61 Cygni—distance is 3.2 parsecs which is 660000 times as far away as the Sun

The Hipparcos satellite(well above Earth’s atmosphere) measured the positions and parallaxes of 120,000 stars. It has an accuracy of 0.002 arcsec.



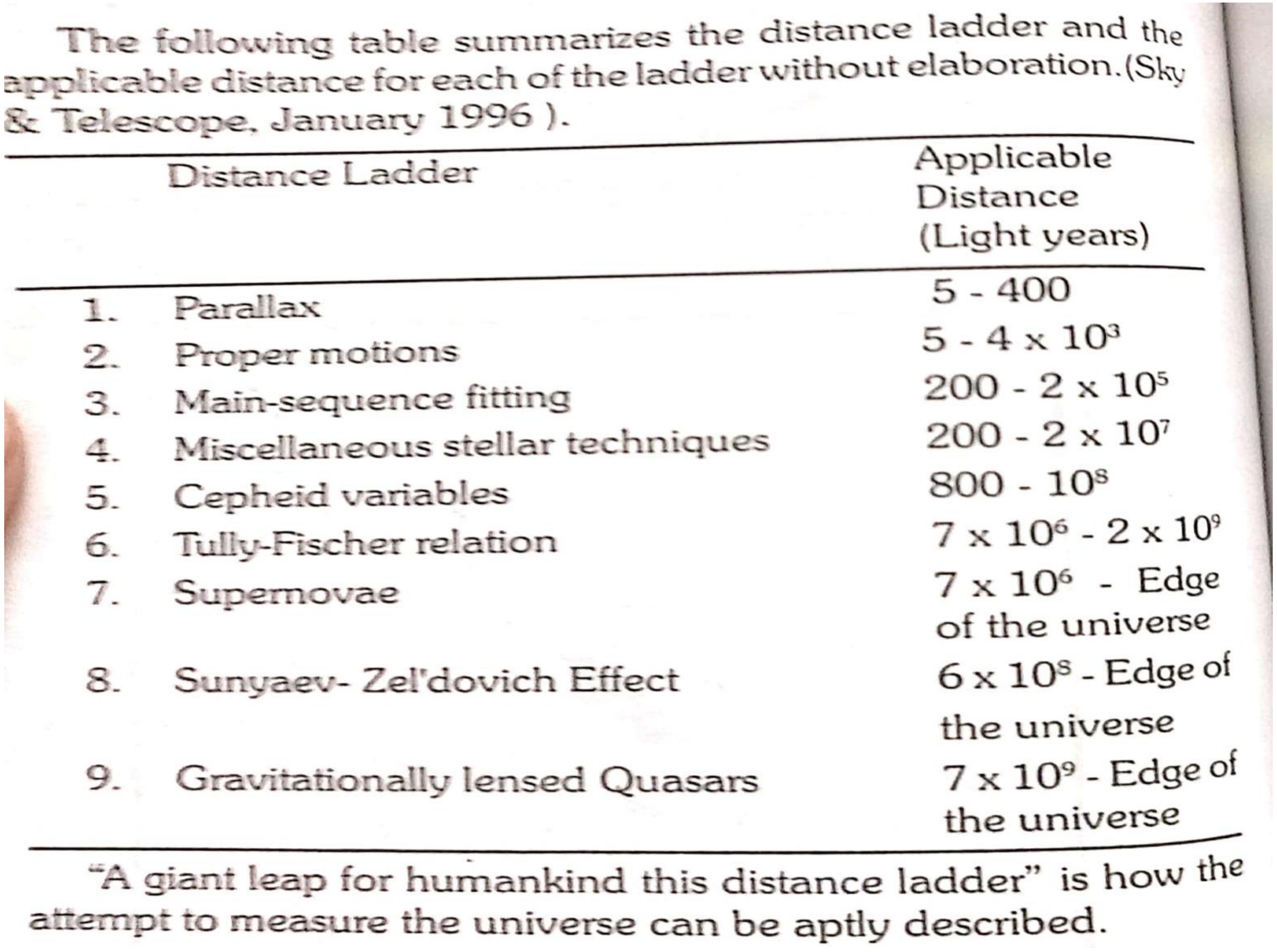
European Space Agency's Hipparcos star-survey satellite(1989-1993)

The famous surveyor's technique of triangulation

- Good only for surveying the neighbourhood of Sun (only within a few hundred light-years)
- Distant stars-------Parallax is too small to measure

Even the nearest stars require a baseline longer than the earth's diameter

DISTANCE LADDER



The following table summarizes the distance ladder and the applicable distance for each of the ladder without elaboration.(Sky & Telescope, January 1996).

	Distance Ladder	Applicable Distance (Light years)
1.	Parallax	5 - 400
2.	Proper motions	5 - 4 x 10^3
3.	Main-sequence fitting	200 - 2 x 10^5
4.	Miscellaneous stellar techniques	200 - 2 x 10^7
5.	Cepheid variables	800 - 10^8
6.	Tully-Fischer relation	7 x 10^6 - 2 x 10^9
7.	Supernovae	7 x 10^6 - Edge of the universe
8.	Sunyaev- Zel'dovich Effect	6 x 10^8 - Edge of the universe
9.	Gravitationally lensed Quasars	7 x 10^9 - Edge of the universe

"A giant leap for humankind this distance ladder" is how the attempt to measure the universe can be aptly described.

Qn: A is twice as far as B. What is parallax of A?

$$d = \left(\frac{2.06\times 10^5\ A.U.}{p}\right)$$

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

If distance increases, parallax decreases

$d_A = 2\ d_B$

$$\frac{p_A}{p_B} = \frac{1/dA}{1/dB} = \frac{d_B}{d_A} = \frac{d_B}{2d_B} = \frac{1}{2}$$

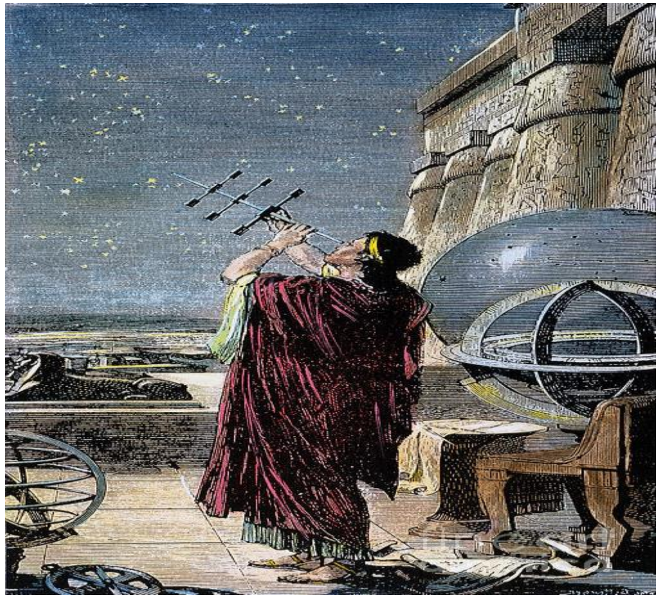
Hence parallax of A decreases

APPARENT BRIGHTNESS

Sometimes referred to as apparent magnitude(m)

- Most information beyond the solar system comes from light emitted by stars, galaxies, and interstellar cloud of gas and dust in every part of the electromagnetic spectrum.
- Apparent brightness is measured in terms of radiant flux
- Radiant flux depends on
    - Distance between the source and the detector
    - Intrinsic luminosity

STELLAR MAGNITUDE SCALE



Hipparchus observed the stars and assigned an apparent magnitude of m=1 to the brightest stars and m=6 to the dimmest stars visible to the naked eye.

Apparent magnitude (*m*)

is a measure of the brightness of a star or other astronomical object.

Depends on luminosity and distance

Not an intrinsic property of emitting object

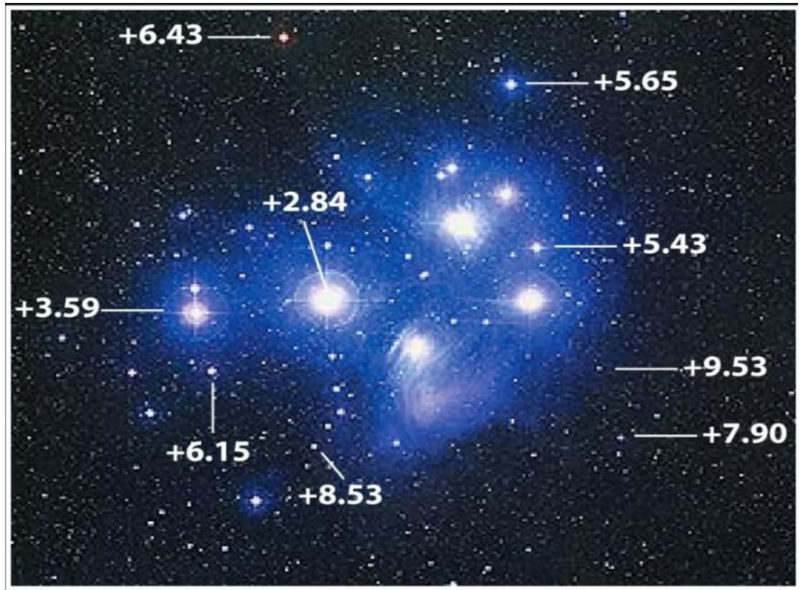
Its interpretation:

Smaller m → a brighter-appearing star

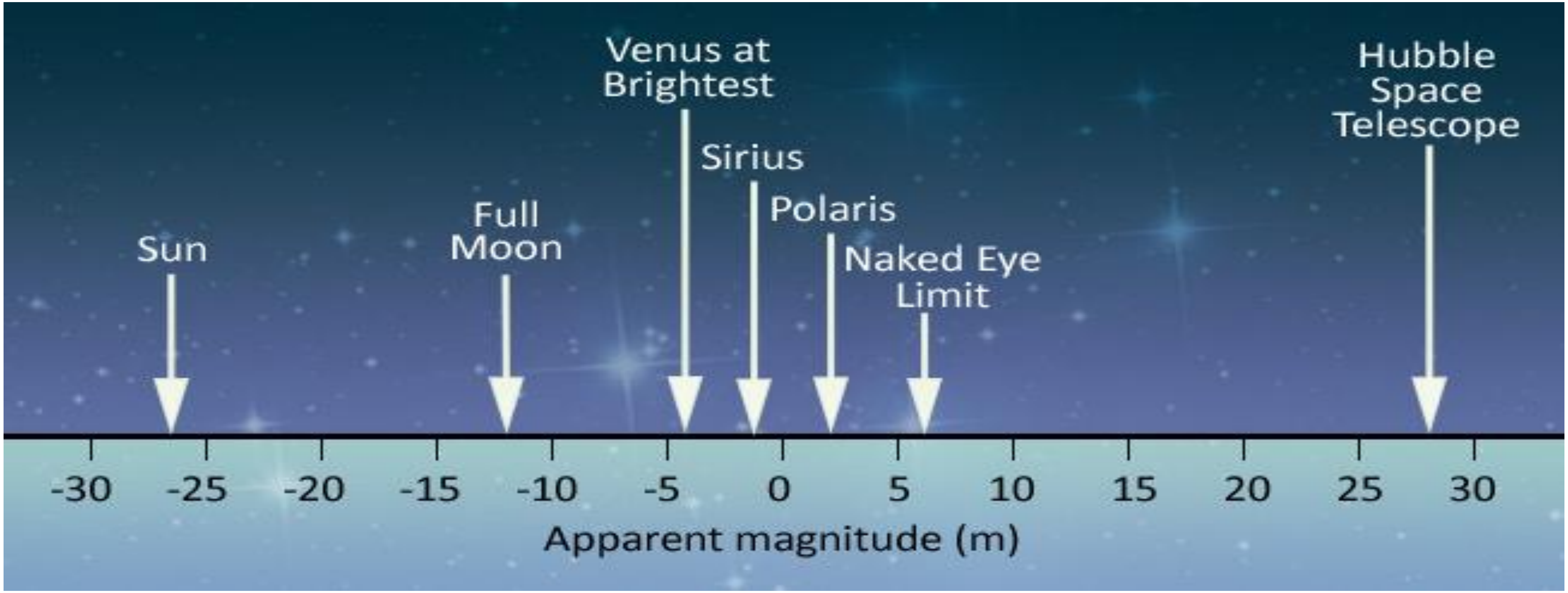
Larger m → a fainter-appearing star

What will negative m imply then?

Brightest ones



Apparent magnitudes of stars in the Pleiades



Brightness increases

QUANTITATIVE INTERPRETATION OF MAGNITUDE SCALE

- A difference of 5 magnitudes corresponds to change in brightness by a factor of 100

  A star of first magnitude appears 100 times brighter than a star of sixth magnitude

- A difference of 1 magnitude corresponds to a brightness ration of $100^{1/5} \cong 2.512$

- A 1st magnitude star appears 2.512 times brighter than a 2nd magnitude star, 2.512^{2} times brighter than a 3rd magnitude star… and so on.

Difference in magnitude	Intensity Ratio
1.0	2.512:1
2.0	6.310:1
3.0	15.85:1
4.0	39.81:1
5.0	100:1
6.0	251.2:1
7.0	631.0:1

Apparent brightness	b_1	b_2
Apparent magnitude	m_1	m_2

$$\frac{b_1}{b_2} = 2.512^{(m_2 - m_1)}$$

$$\frac{b_1}{b_2} = 100^{\frac{(m_2 - m_1)}{5}}$$

$$m_2 - m_1 = 2.5\, log_{10} \frac{b_1}{b_2}$$

Star A has magnitude +5, Star B has magnitude +10. Which of the stars is brighter and by how much?

- ***Smaller the magnitude, the brighter it is . So A is brighter than B.***
- ***The magnitude difference is 10-5 = 5. So A is 100 times brighter than B***

ONCE DISTANCE AND BRIGHTNESS ARE KNOWN **LUMINOSITY** CAN BE CALCULATED

ABSOLUTE MAGNITUDE(M)- MEASURE OF LUMINOSITY(L)

- The apparent magnitude of a star when it is brought to a fixed distance (10pc) from the Earth

To know about the stars themselves we need to know about total energy radiated by the star per sec i.e., L

- Luminosity is the Total energy emitted per second

  It does not depend on distance

  Intrinsic property of emitting object

- Sometimes referred to as

  Absolute magnitude

  Intrinsic Luminosity

What L tells us?

- *Rate at which a star is burning its nuclear fuel .*
- *Very high L --------- Die soon and vice-versa*
- *Tells us the Rate at which a star is aging*

FLUX, LUMINOSITY AND THE INVERSE SQUARE LAW

Brightness is measured in terms of radiant flux

Flux at a distance r is related to the star's luminosity by

$$\text{Flux(F)} = \frac{\text{Luminosity(L)}}{4\pi r^2}$$

$$\mathbf{F} \propto \frac{1}{r^2}$$

Since L is independent of r

Inverse square law for light

relates the intrinsic properties of a star(L and M) to the quantities that are measured at a distance from the star(radiant flux and m)

Connection between m and M

$$m_2 - m_1 = 2.5\, log_{10} \frac{b_1}{b_2}$$

$$m_2 - m_1 = 5\, log_{10} \frac{r_2}{r_1}$$

Since **F** $\propto \frac{\mathbf{1}}{\boldsymbol{r}^{\mathbf{2}}}$

For a star with apparent magnitude m and absolute magnitude M

$$\mathrm{m} - M = 5\, log_{10} \frac{r}{10pc}$$

← Actual distance of the star

$$r = 10\, pc\ \times 10^{\frac{m-M}{5}}$$

Distance can also be calculated from the distance modulus relation

$$r = 10\,pc\ \times 10^{\frac{m-M}{5}}$$

Here m-M is called the distance modulus because it is directly related to the star’s distance

If a star’s m and M are known then the star’s actual distance r can be calculated

If one knows r, then measuring m one can get the value of M

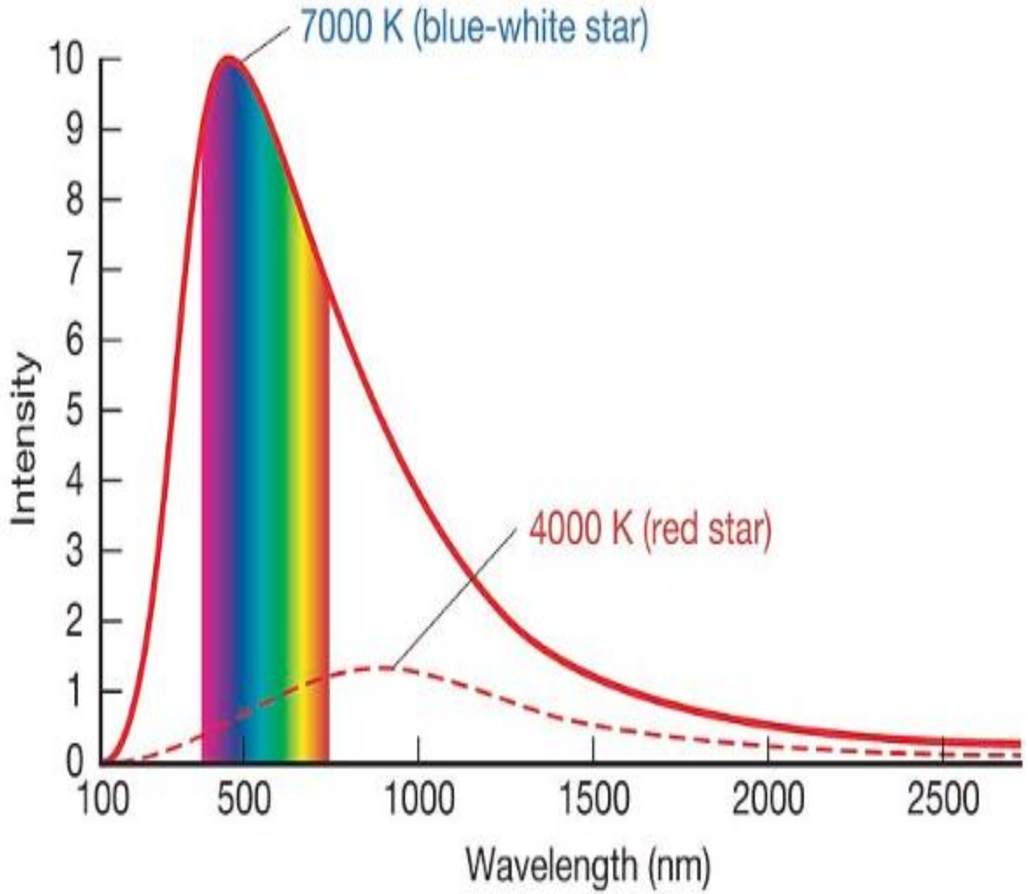
RADIATION TELLS US THE **TEMPERATURE, SIZE** AND **COMPOSITION** OF STARS.

TEMPERATURE AND RADIUS

- Stars and planets are black body at least to a rough first approximation
- So one can use
  - ***Wien's displacement law*** ---allow us to measure the T of stars
  - ***Stefan's law*** ---measure size of stars

Wien's displacement law

$$\lambda_{max}T = constant$$
$$= 0.0029\, m\ K$$



Connection between color and temperature

$$\lambda_{max}T = constant$$
$$= 0.0029\ m\ K$$

λ_{max} for Betelgeuse = 805 nm

$T_{surface}$ = 3600 K

Betelgeuse appears red

λ_{max} for Rigel = 223 nm

$T_{surface}$ = 13000K

Rigel appears blue-white

- The spectra of stars were first classified during the late 1800s well before stars or atoms or radiation were well understood

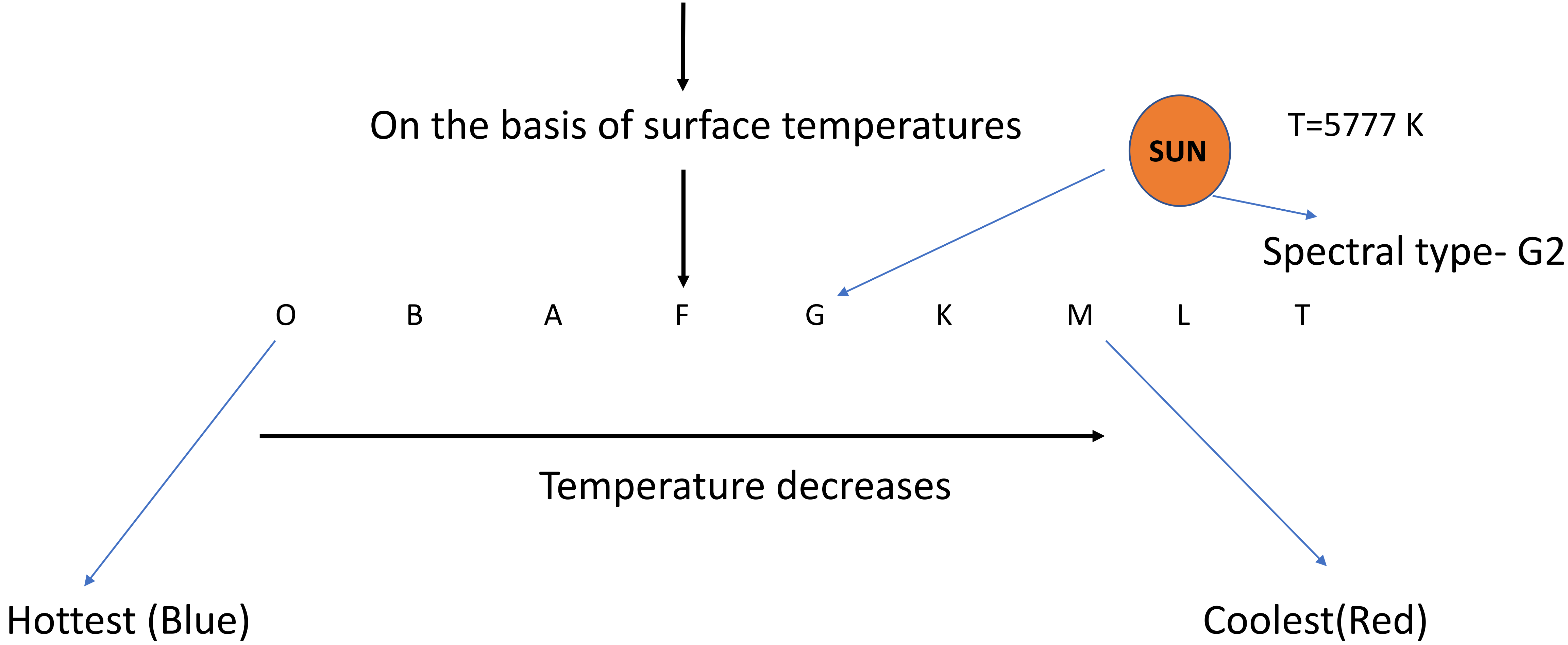
- The original ordering of this classification was arbitrarily based on the prominence of particular absorption lines known to be associated with the element H

- Stars with the strongest H lines were labelled as A stars, stars with somewhat weaker H lines as B stars and so on.

- Earlier classification refined by Annie Jump Cannon in 1901
- Classified the stars into 7 classes systematically on the basis of surface temperatures.
- Different spectral lines are formed at different T ,so the absorption lines in a star’s spectra can be used to measure the stars T

- Details of absorption and emission lines in starlight carry a wealth of information .
- Most stellar atmospheres are primarily composed of H and He

STELLAR CLASSIFICATION



On the basis of surface temperatures

T=5777 K

Spectral type- G2

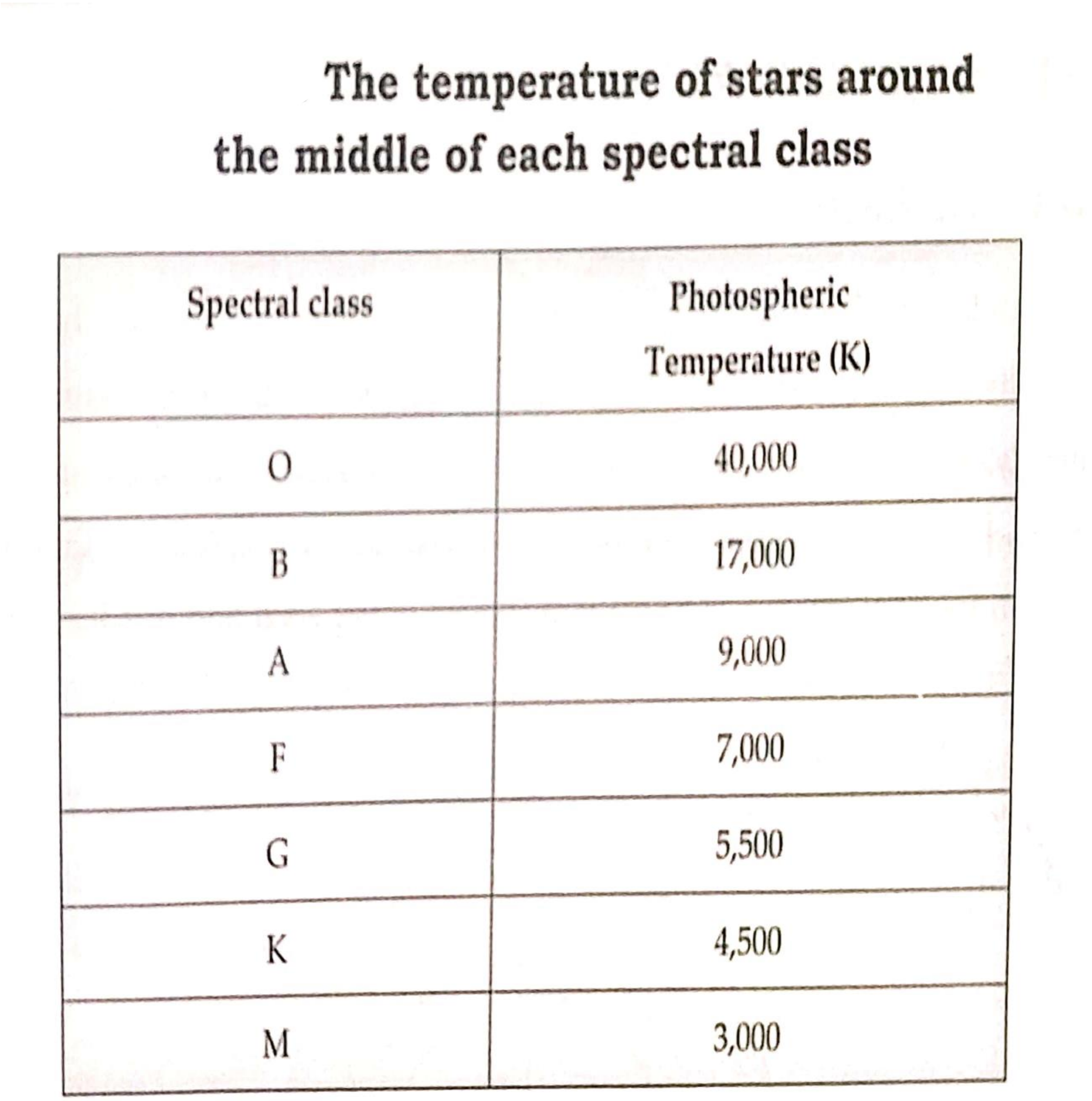
O B A F G K M L T

Temperature decreases

Hottest (Blue)

Coolest(Red)

SPECTRAL TYPE	COLOR
O	Hottest blue-white stars
B	Hot blue-white
A	White
F	Yellow- White
G	Yellow
K	Cool Orange
M	Cool Red
L	Very cool, dark red
T	Coolest, IR



The temperature of stars around the middle of each spectral class

Spectral class	Photospheric Temperature (K)
O	40,000
B	17,000
A	9,000
F	7,000
G	5,500
K	4,500
M	3,000

For a spherical star of radius R and surface area A= $4\pi R^2$, **the** *Stefan-Boltzmann equation* **is**

$$\textbf{Luminosity} = 4\pi R^2 \sigma Teff^4$$

calculate

$$\text{Flux}= \frac{\text{Luminosity(L)}}{4\pi r^2}$$

$$\lambda_{max} T = constant = 0.0029\ m\ K$$

$$\boxed{R = \frac{1}{T^2}\sqrt{\frac{L}{4\pi\sigma}}}$$

If two stars have the same temperature or of the same spectral type then the one with high luminosity must be larger

- STEFAN-BOLTZMANN LAW can also give the T_{eff}

For a spherical star of radius R and surface area A= **4 π R^2, the Stefan-Boltzmann equation is**

$$\textbf{Luminosity} = 4\pi R^2 \,\sigma\, Teff^4$$

If L and R or Flux for a star is known then T_{eff} can be calculated

Sirius A and Sirius B have $T_{eff} = 10000^0$K

Sirius B is 10 magnitude fainter than Sirius A

Find the radius of Sirius B??

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

$$\frac{4\pi RB^2 \sigma Teff^4}{4\pi RA^2 \sigma Teff^4} = \frac{L_B}{L_A}$$

$$\frac{R_B{}^2}{R_A{}^2} = \frac{10^{-4}\ L_A}{L_A} = 10^{-4}$$

$$R_B = 10^{-2} R_A$$

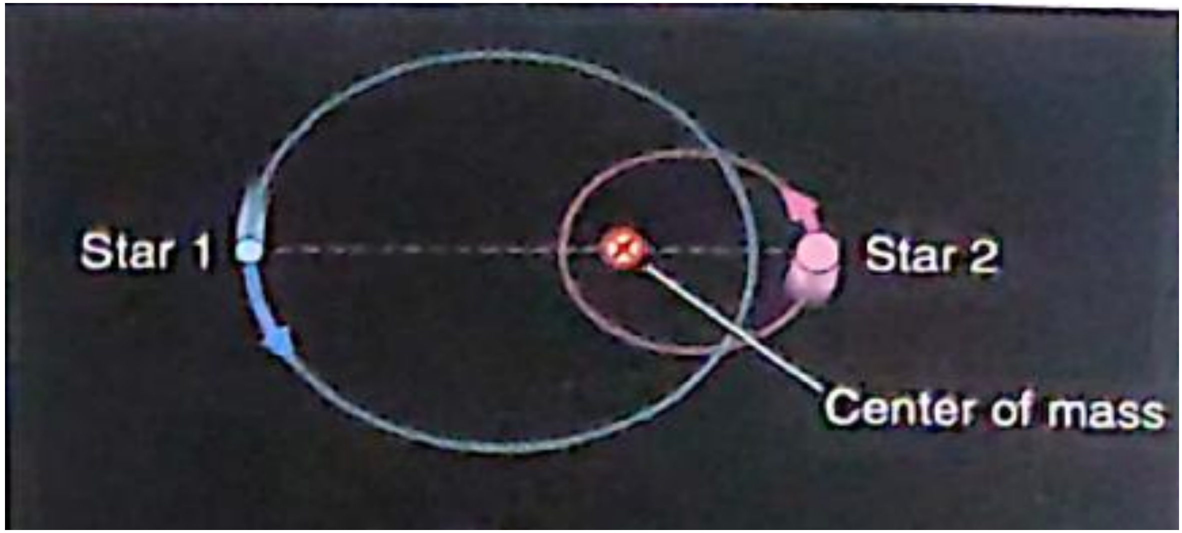
MASS

- A star’s mass at birth determines the basic essentials of its structure and future life.

- The behavior of stellar parameters with stellar mass is different for the higher-mass stars ((25-120) M_{Sun}) than for the solar type stars ((0.8-1.2) M_{Sun}

MEASUREMENT OF STELLAR MASS

Direct method- Kepler's 3rd Law:



Total mass of the binary

- $$T^2 = \frac{4\pi^2 a^3}{G(m_1+m_2)} \qquad (1)$$

If we know the velocities then

- $$\frac{m_1}{m_2} = \frac{v_2}{v_1} \qquad (2)$$

Combining (1) and (2) we can know the individual masses

MEASUREMENT OF STELLAR MASS

Indirect method-Stellar models

T_{eff} and L are known → from spectroscopic observations

Distance is known → from parallax

g(Surface gravity) is known → from model - fitting

$$R = \frac{1}{T_e^2}\sqrt{\frac{L}{4\pi\sigma}}.$$

$$g \sim \frac{M}{R^2}$$

Radius can be obtained

Get the value of M

CHEMICAL COMPOSITION

- Stars vary in chemical composition

- The chemical composition of most stars is

  73 % H
  25% He
  2% other elements

Each star has its own different spectra

- Absorption lines occur when light passes through a cloud of gas, and the atoms and molecules of the gas absorb some light at some specific wavelengths, characteristics of the kind of the atoms and molecules.

- Similarly the atoms and molecules in a diffused hot gas will emit light at specific wavelengths.

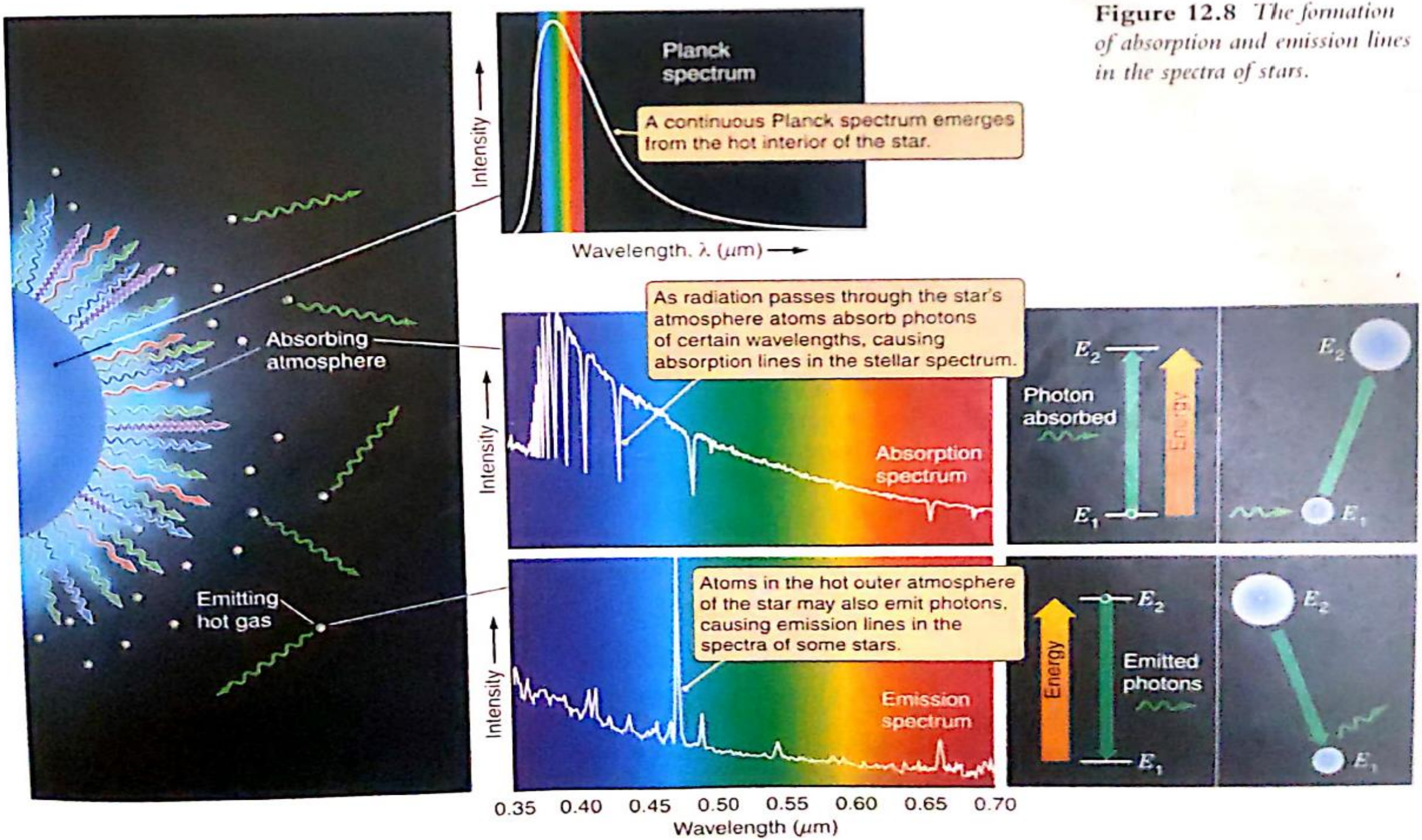
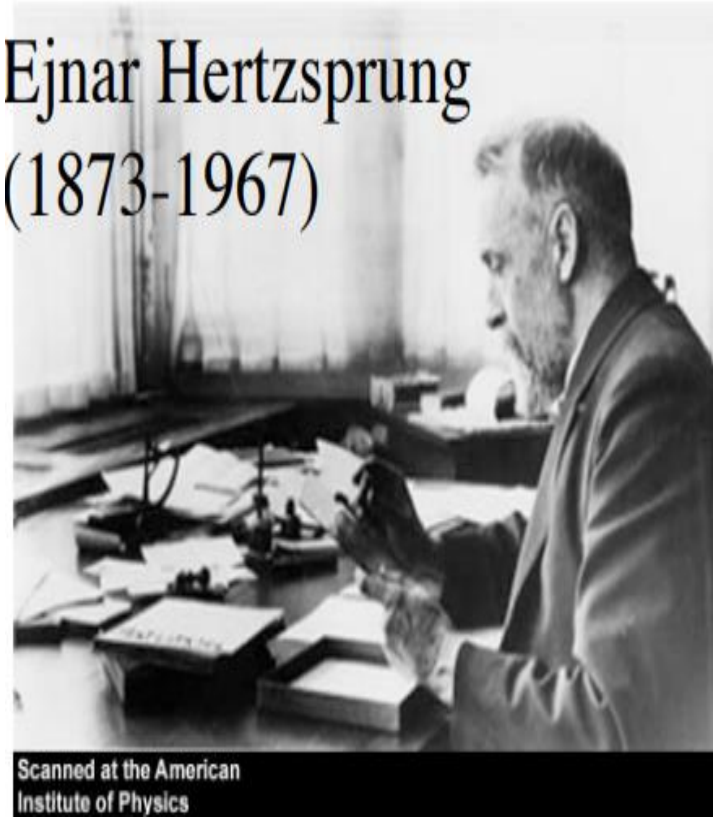


Figure 12.8 *The formation of absorption and emission lines in the spectra of stars.*

HERTZSPRUNG-RUSSELL DIAGRAM


Ejnar Hertzsprung
(1873-1967)

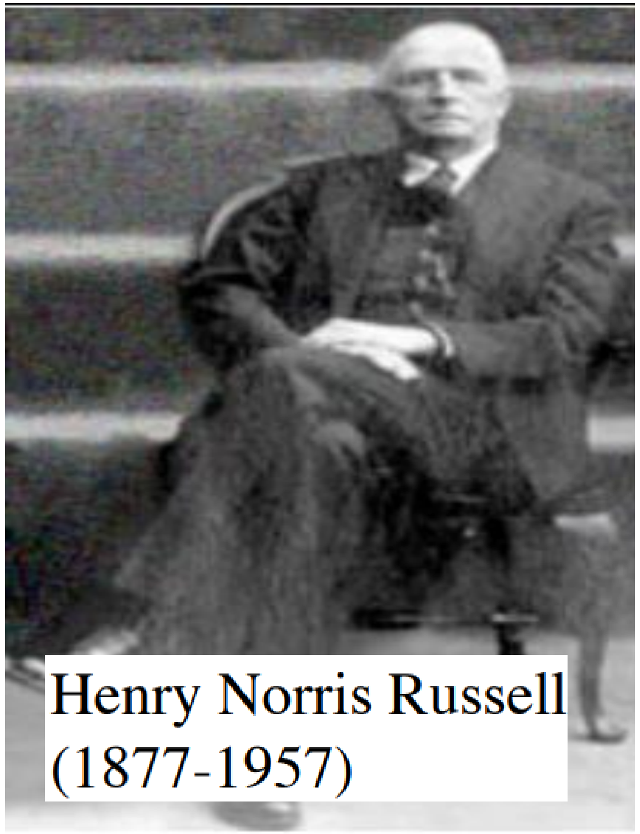
Scanned at the American Institute of Physics

Plot between

- Luminosity(L) or Absolute magnitude (M) and
- Effective Temperature or surface temperature (spectral class)

↓

H-R Diagram


Henry Norris Russell
(1877-1957)

- Each dot is a star
- Snapshot of stars → *INTERPRETATION?*
- No random distribution-> there exists a relation between a star's L and T
- 90% stars-------**Main sequence band**

  ↓

  - Massive and more luminous at upper left
  - less massive and low luminosity towards bottom right
- 10% stars → upper right

  → **Red Giants** and **supergiants**

  ↓ ↓

  Betelgeuse

  Largest of all stars
- White dwarfs → extremely dense
- Check theories of stellar evolution
- Check internal structures of stars
- Know the position in H-R Diagram-> know its L, size and surface temperature

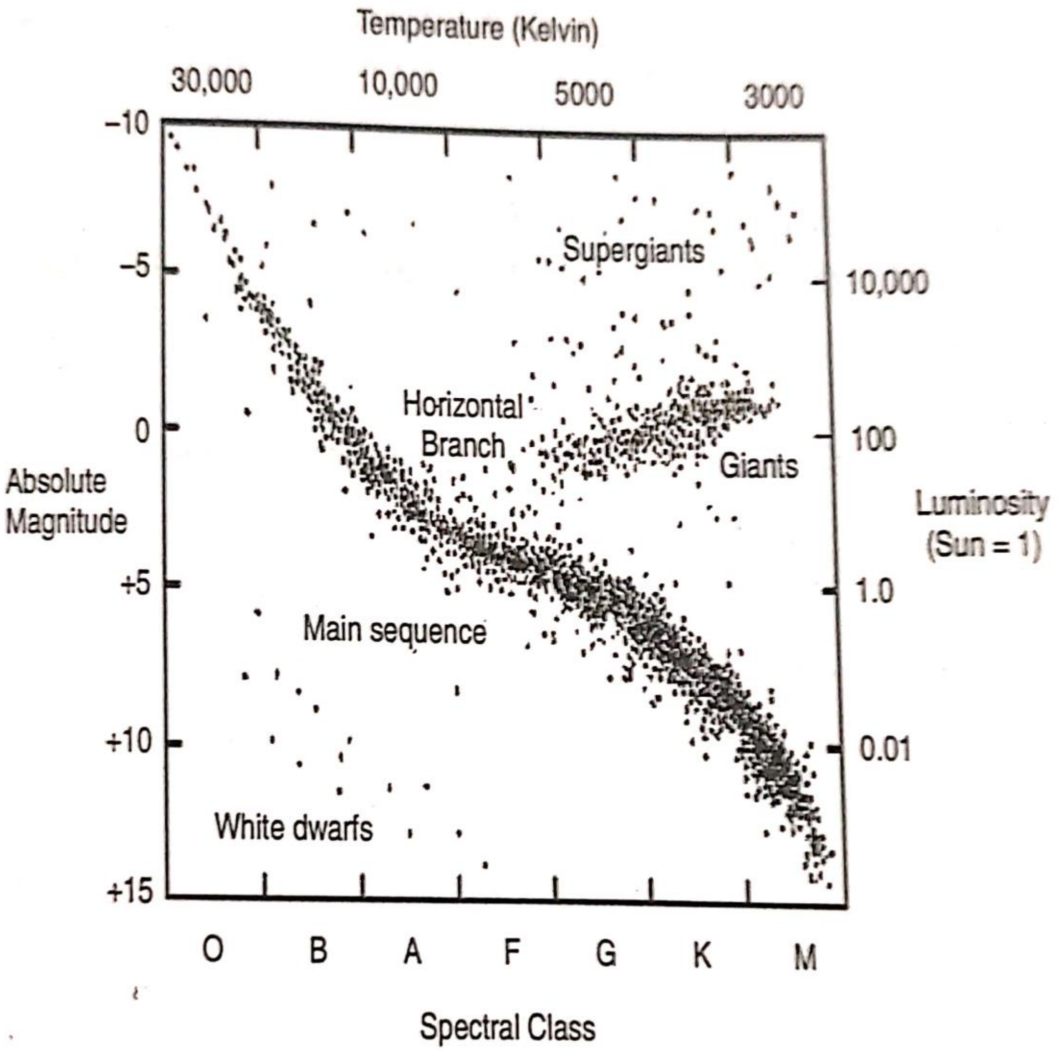


Figure 1.9: Hertzprung-Russell (H-R) Diagram.

- *From the HR diagram we can measure---------- radius*
- Since each dot is specified by a surface temperature and luminosity we can measure the radius of a star using

$$\textbf{Luminosity} = 4\,\pi\,R^2\;\sigma\,Teff^4$$

Right top-> high L-> low T, so R high->giants

Left bottom-> low L-> high T, so R low-> White dwarfs

From the HR diagram we can measure----------- distance to a star

Pick a star in H-R diagram

↓

Get to know its Luminosity(L)

- from observation obtain the flux(or brightness)

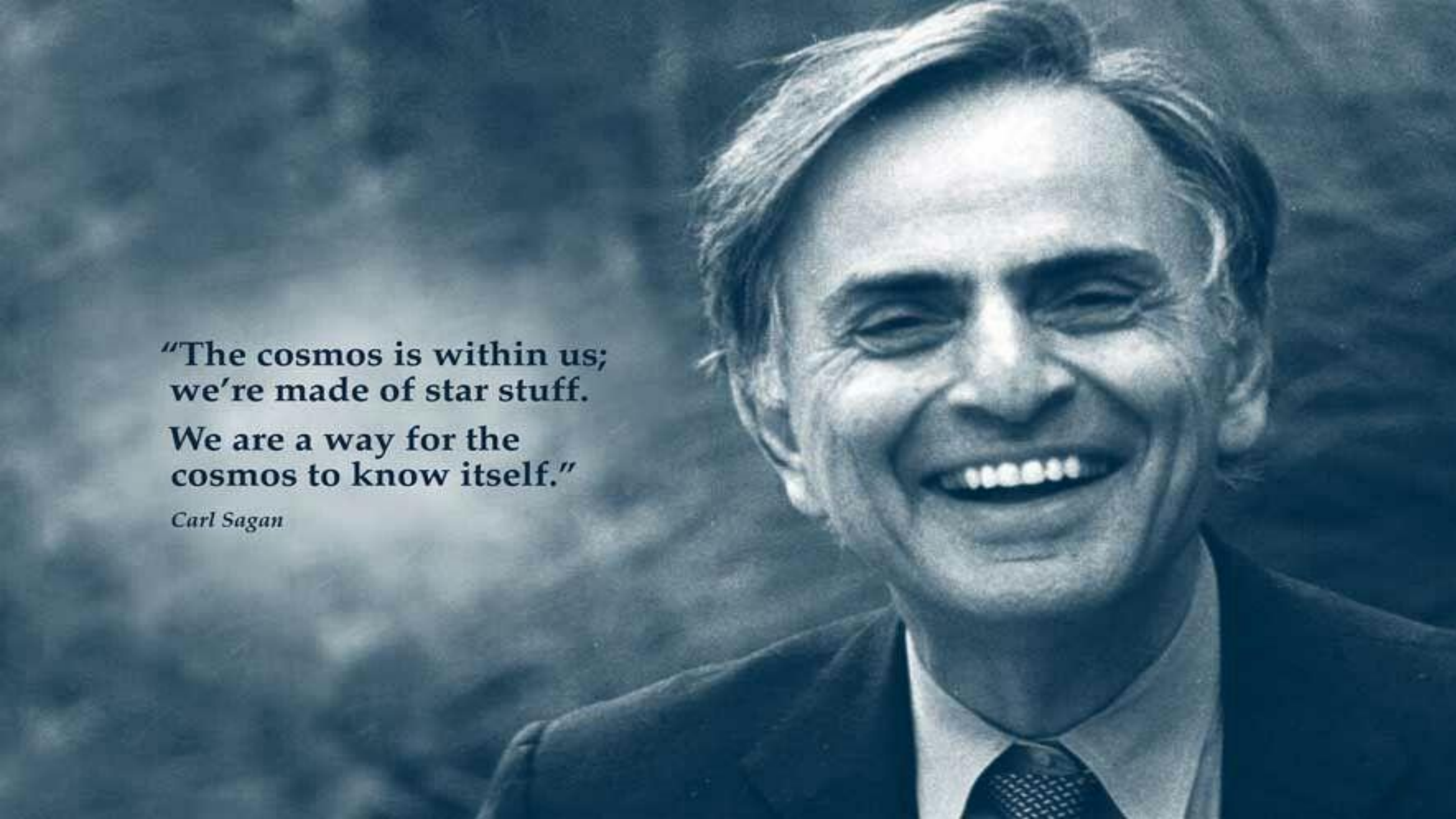
$$\text{Flux} = \frac{\text{Luminosity(L)}}{4\pi r^2}$$

← Calculate Distance

- This method known as spectroscopic parallax → probes vast distances of galaxies (our and nearby)

A brief summary of the method used to measure the basic properties of a star

Property	Method
Distance(d)	Parallax, Spectroscopic Parallax
Luminosity(L)	If d is known, measure brightness and use $L=4\pi \times \text{distance}^2 \times \text{brightness(flux)}$
Temperature(T_{eff})	Wien’s law
Size(Radius)	If L and T_{eff} is known, use Stefan’s law
Mass(M)	Kepler’s law
Composition	Knowing the T_{eff} of a star, analyze the lines in its spectrum to measure chemical composition



> “The cosmos is within us;
> we’re made of star stuff.
>
> We are a way for the
> cosmos to know itself.”
>
> *Carl Sagan*