WELCOME

ASTRONOMICAL PARAMETRES

<u>ASTRONOMICAL SCALES</u> :

* **<u>Structure</u> :-**

- Astronomical Distance, Mass and Time Scales
- Brightness, Radiant Flux and Luminosity

Measurement of Astronomical Quantities

- Astronomical Distances
- Stellar Radii
- Masses of Stars
- Stellar Temperature

ASTRONOMICAL DISTANCE, MASS AND TIME SCALES :

- In astronomy, we are interested in measuring various physical quantities, such as mass, distance, radius, brightness and luminosity of celestial objects.
- The scales at which these quantities occur in astronomy are very different from the ones we encounter in our day-to-day lives.

- Hence, we first need to understand these scales and define the units of measurement for important astrophysical quantities.

- **<u>Astronomical Distances</u> :**

We’ve studied that the Sun is at a distance of about 1.5 × 10^{11}m from the Earth.

- The mean distance between the Sun and the Earth is called one **astronomical unit**.

Distances in the solar system are usually measured in this unit.

- Another unit is the **light year**, used for measuring distances to stars and galaxies.
- The **parsec** is a third unit of length measurement in astronomy.

- Now to define them :

Units of measurement of distances

- 1 **Astronomical Unit** (AU) is the mean distance between the Sun and the Earth.

  $$\mathbf{1\ AU = 1.496 \times 10^{11} m}$$

- 1 **Light Year** (ly) is the distance travelled by light in one year.

  $$\mathbf{1\ ly = 9.460 \times 10^{15} m = 6.323 \times 10^{4}\ AU}$$

- 1 **Parsec** (pc) is defined as the distance at which the radius of Earth's orbit subtends an angle of 1″ (see Fig.1.1).

  $$\mathbf{1\ pc = 3.262\ ly = 2.062 \times 10^{5} AU = 3.085 \times 10^{16} m}$$

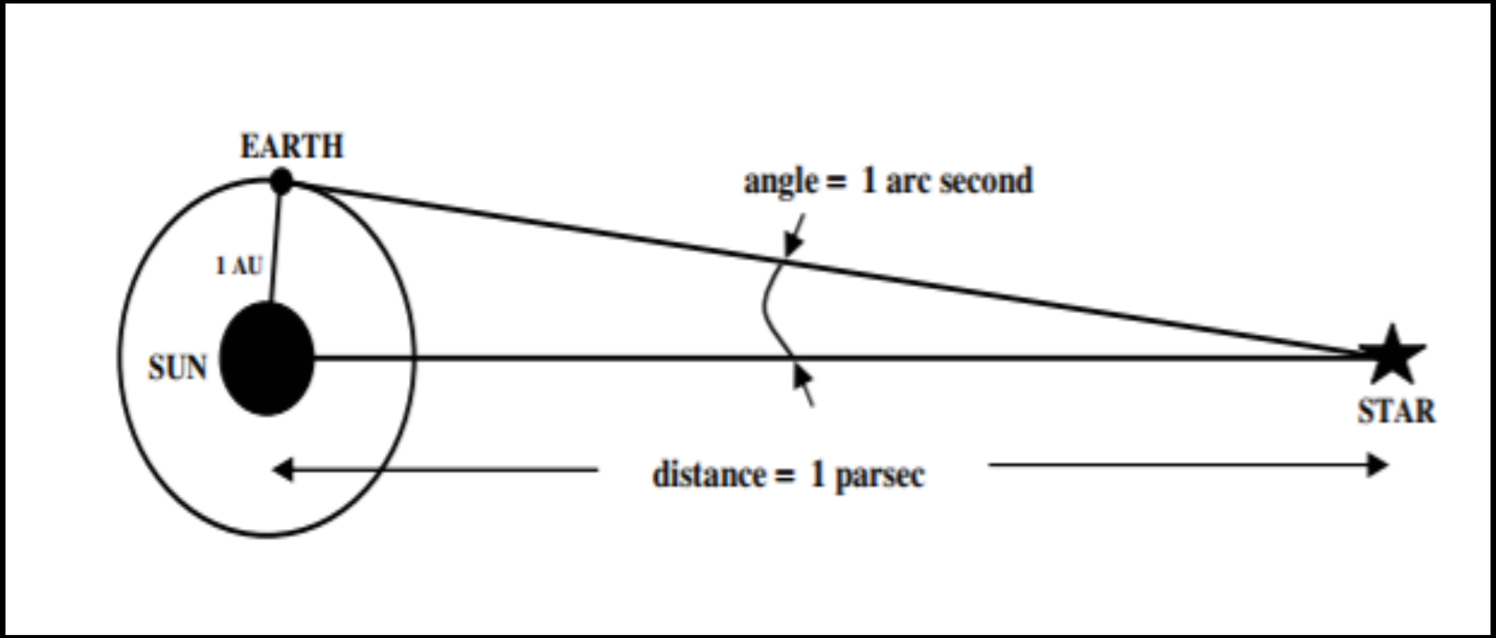


diagram showing the definition of 1 parsec.

Note :

$1^\circ \equiv 60' \; ;1' = 60''$

Thus : 1 $''$ = 1/3600 degree

DIMENSIONS OF ASTRONOMICAL OBJECTS :

- The sizes of stars or stellar dimensions are usually measured in units of solar radius R_{Θ} .
- For example: Sirius, the brightest star in the sky, has radius 2 R_{Θ}.

Unit of measurement of size

1 solar radius, $R_{\Theta} = 7 \times 10^{8}$ m

MASS :

- **Stellar masses** are usually measured in units of solar mass M_{Θ}.
- We know that M_{Θ} = 2 × 10^{30} kg.

- For example: the mass of our galaxy is ~ $10^{11}\ M_{\Theta}$.

Unit of measurement of mass

1 solar mass $M_{\Theta} = 2 \times 10^{30}$ kg

TIME SCALES :

The present age of the Sun is about 5 billion years. It has been estimated that it would live for another 5 billion years in its present form.

The age of our galaxy may be around 10 billion years. Various estimates of the age of the universe itself give a figure between 12 and 16 billion years.

On the other hand, if the pressure inside a star is insufficient to support it against gravity, then it may collapse in a time, which may be measured in seconds, rather than in millions of years

Distance, radii and masses of astronomical objects :

	Distance	Radius	Mass	Remarks
Sun	1 AU	$1\ R_\Theta$	$1\ M_\Theta$	–
Earth	–	$0.01\ R_\Theta$	$10^{-6}\ M_\Theta$	–
Jupiter	4 AU (5 AU from the Sun)	$0.1\ R_\Theta$	$10^{-3}\ M_\Theta$	Largest planet
Proxima Centauri	1.3 pc	$0.15\ R_\Theta$	$0.12\ M_\Theta$	Nearest star
Sirius A	2.6 pc	$2\ R_\Theta$	$3\ M_\Theta$	Brightest star
Sirius B	2.6 pc	$0.02\ R_\Theta$	$1\ M_\Theta$	First star identified as white dwarf
Antares	150 pc	$700\ R_\Theta$	$15\ M_\Theta$	Super giant star

BRIGHTNESS, RADIANT FLUX AND LUMINOSITY :

- A star might look bright because it is closer to us. And a really brighter star might appear faint because it is too far.

- We can estimate the apparent brightness of astronomical objects easily, but, if we want to measure their **real or intrinsic brightness**, we must take their distance into account.

- The **apparent brightness** of a star is defined in terms of what is called the **apparent magnitude** of a star.

APPARENT MAGNITUDE :

- In the second century B.C., the Greek astronomer **Hipparchus** was the first astronomer to catalogue stars visible to the naked eye. He divided stars into six classes, or **apparent magnitudes**, by their relative brightness as seen from Earth.
- He numbered the apparent magnitude (m) of a star on a scale of **1** (the brightest) to **6** (the least bright). This is the scale on which the apparent brightness of stars, planets and other objects is expressed as they appear from the Earth.
- The brightest stars are assigned the **first magnitude** (m = 1) and the **faintest stars** visible to the naked eye are assigned the **sixth magnitude** (m = 6).

Apparent Magnitude

Apparent magnitude **of an astronomical object is a measure of how bright it** ***appears*****. According to the magnitude scale,** ***a smaller magnitude means a brighter star*****.**

- The magnitude scale is actually a **non-linear** scale. This means is that a star, two magnitudes fainter than another, is not twice as faint.
- Actually it is about 6.3 times fainter.
- So, we define a **logarithmic scale for magnitudes** in which a **difference of 5 magnitudes is equal to a factor of 100 in brightness**. On this scale, the brightness ratio corresponding to 1 magnitude difference is $100^{\frac{1}{5}}$ or 2.512.
- Therefore, a star of magnitude 1 is 2.512 times brighter than a star of magnitude 2.

Relationship between brightness and apparent magnitude :

$$m_1 - m_2 = 2.5 log_{10}\left(\frac{b_1}{b_2}\right)$$

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

Magnitude Difference	Brightness Ratio
0.0	1.0
0.2	1.2
1.0	2.5
1.5	4.0
2.0	6.3
2.5	10.0
3.0	16.0
4.0	40.0
5.0	100.0
7.5	1000.0
10.0	10000.0

Brightness ratio corresponding to given magnitude difference

Luminosity and Radiant flux :

- The apparent magnitude and brightness of a star do not give us any idea of the total energy emitted per second by the star. This is obtained from **radiant flux** and the **luminosity** of a star.
- The *luminosity* of a body is defined as **the total energy radiated by it per unit time**.
- ***Radiant flux*** at a given point is the **total amount of energy flowing through per unit time per unit area of a surface oriented normal to the direction of propogation of radiation**.

- The unit of **radiant flux** is **erg/s** cm^2 and that of **luminosity** is **erg/s** .

here, the radiated energy refers to not just visible light, but includes all wavelengths.

The radiant flux of a source depends on two factors:

(i) the radiant energy emitted by it, and

(ii) the distance of the source from the point of observation.

Suppose a star is at a distance r from us. Let us draw an imaginary sphere of radius r round the star. The surface area of this sphere is $4\pi r^2$. Then the radiant flux **F** of the star, is related to its luminosity **L** as follows:

$$F = \frac{L}{4\pi r^2}$$

The **luminosity** of a stellar object is a measure of the intrinsic brightness of a star. It is expressed generally in the units of the **solar luminosity**, L_{Θ}, where :

$$L_{\Theta} = 4 \times 10^{26} W = 4 \times \ 10^{33} \text{ erg/s}$$

For example, the luminosity of out galaxy is about $10^{11} L_{\Theta}$.

Now, the energy from a source received at any place, determines the brightness of the source.

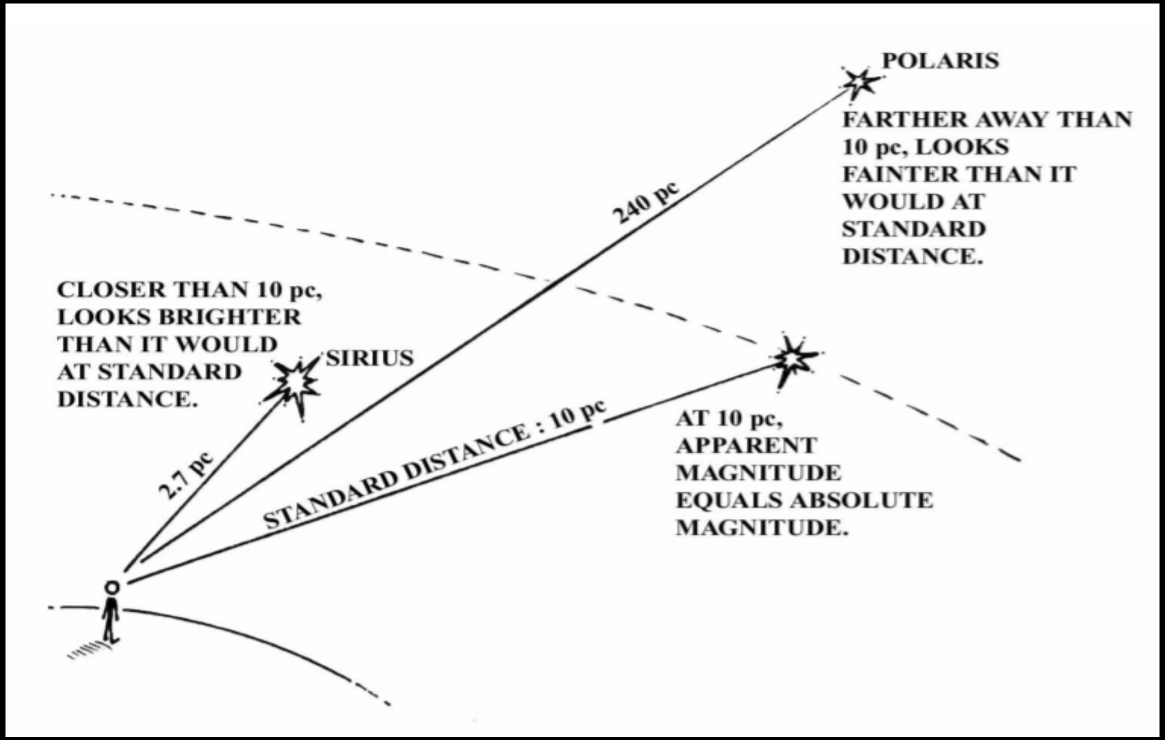
This implies that **F** is related to the brightness **b** of the source: the brighter the source, the larger would be the radiant flux at a place.

Therefore, the ratio of brightness in the previous equation can be replaced by the ratio of radiant flux from two objects at the same place and we have

$$\frac{F_2}{F_1} = 100^{\left(\frac{m_1 - m_2}{5}\right)}$$

Absolute Magnitude

The *absolute magnitude*, *M*, of an astronomical object is defined as its apparent magnitude if it were at a distance of 10 pc from us.



Absolute magnitude of astronomical objects

- Now, to relate the absolute magnitude of a star to its apparent magnitude,

let us consider a star at a distance **r** pc with apparent magnitude **m**, luminosity **L** and radiant flux **F1**. Now when the same star is placed at a distance of **10 pc** from the place of observation, then its magnitude would be **M** and the corresponding radiant flux would be **F2**.

So, as seen earlier, we have : $\dfrac{F_2}{F_1} = 100^{\frac{m-M}{5}}$

And since luminosity is constant for the star, we can write :

$$\frac{F_2}{F_1} = \left(\frac{r\ pc}{10\ pc}\right)^2$$

from the above two equations, we get the difference between the **apparent magnitude (m)** and **absolute magnitude (M).**

It is a measure of **distance** and is called the **distance modulus.**

Distance modulus

$$m - M = 5\log_{10}\left(\frac{r\,\mathrm{pc}}{10\,\mathrm{pc}}\right) = 5\log_{10} r - 5 \qquad (1.7)$$

$$\frac{L_2}{L_1} = 100^{\frac{M_1 - M_2}{5}}$$

(or)

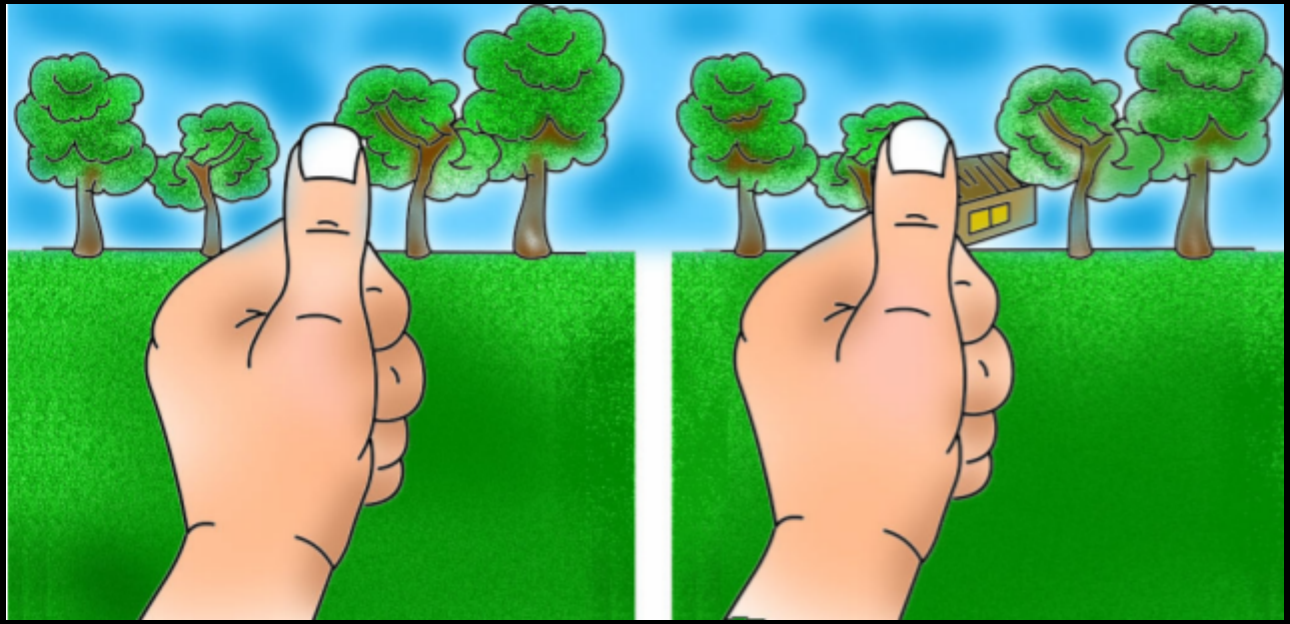
$$M_1 - M_2 = 2.5 log_{10}\left(\frac{L_2}{L_1}\right)$$

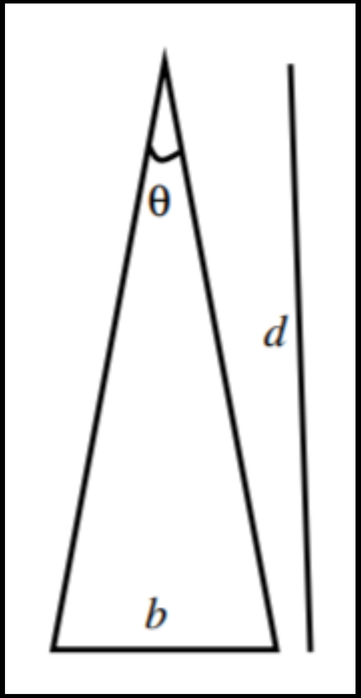
Thus, the absolute magnitude of a star is a measure of its **luminosity**, or **intrinsic brightness**.

MEASUREMENT OF ASTRONOMICAL QUANTITIES :

- **ASTRONOMCAL DISTANCES**

Trigonometric Parallax :





Let θ represent the apparent shift in position of the thumb.

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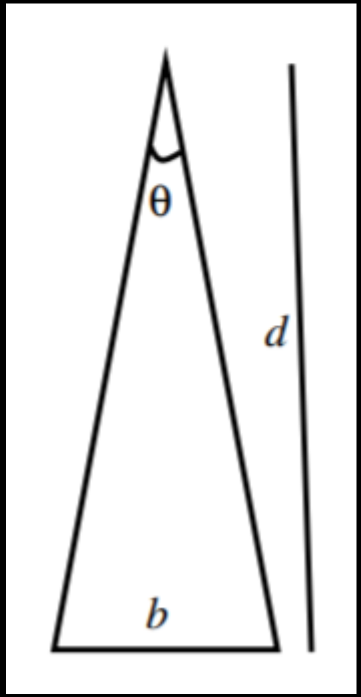


we define the angle $\theta/2$ as the **parallax angle.**

The distance **b** between the points of observation (in this case your eyes), is called the **baseline**.

From simple geometry, for small angles,

$\frac{\theta}{2} = \frac{b}{d}$, where **d** is the distance from the eyes to the thumb.

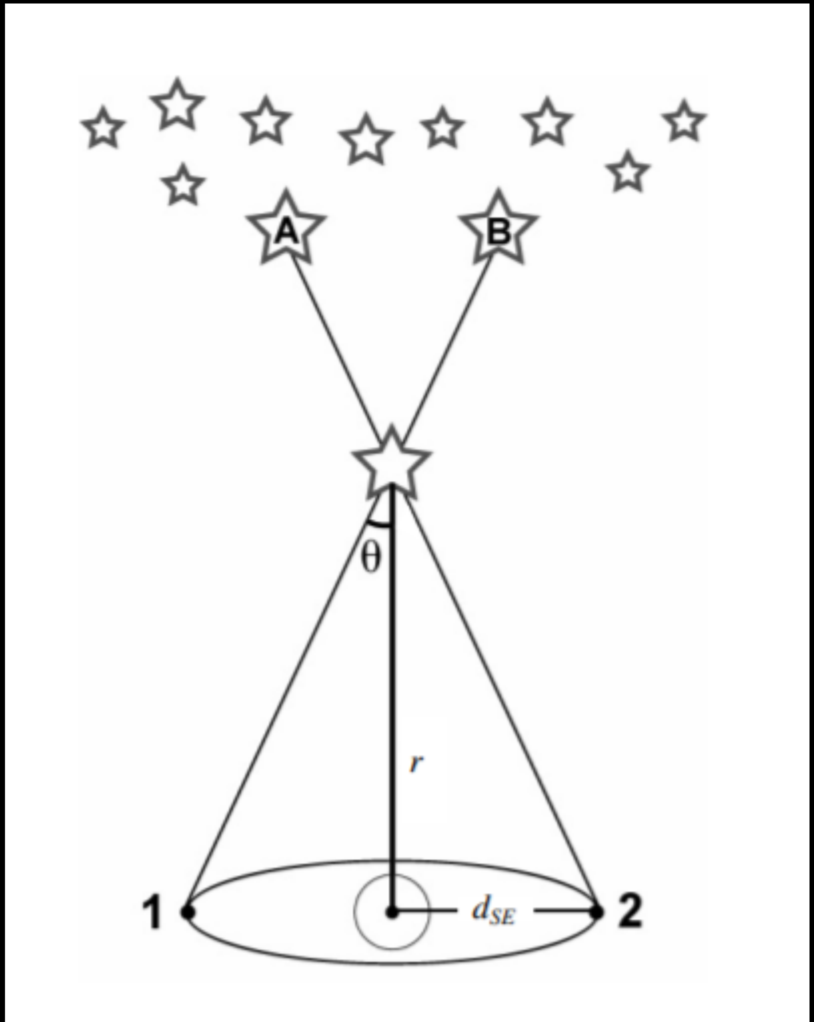
The parallax method can be used to measure the distances of stars and other objects in Astronomical Scales the sky.

STELLAR PARALLAX :

- For measuring the distance of a star, we must use a very long baseline. This is because the distance of star is very large so large that the angle measured from two diametrically opposite points on the Earth will differ by an amount which cannot be measured.

- Therefore, we take the **diameter of the Earth's orbit** as the baseline, and **make two observations** at an interval of six months.

- One half of the maximum change in angular position (Fig. 1.5) of the star is defined as its **annual parallax.**



stellar parallax

$$\frac{d_{sE}}{r} = Tan\theta$$

where d_{sE} is the average distance between the Sun and the Earth. Since the angle θ is very small, tan θ ≅ θ,

and we can write : $r = \frac{d_{sE}}{\theta}$

Since, d_{sE} = 1 AU, we have :

$$r = \frac{1AU}{\theta}$$ (θ is in arc seconds)

One parsec is the distance of an object that has a *par*allax of one *sec*ond of an arc (1″).

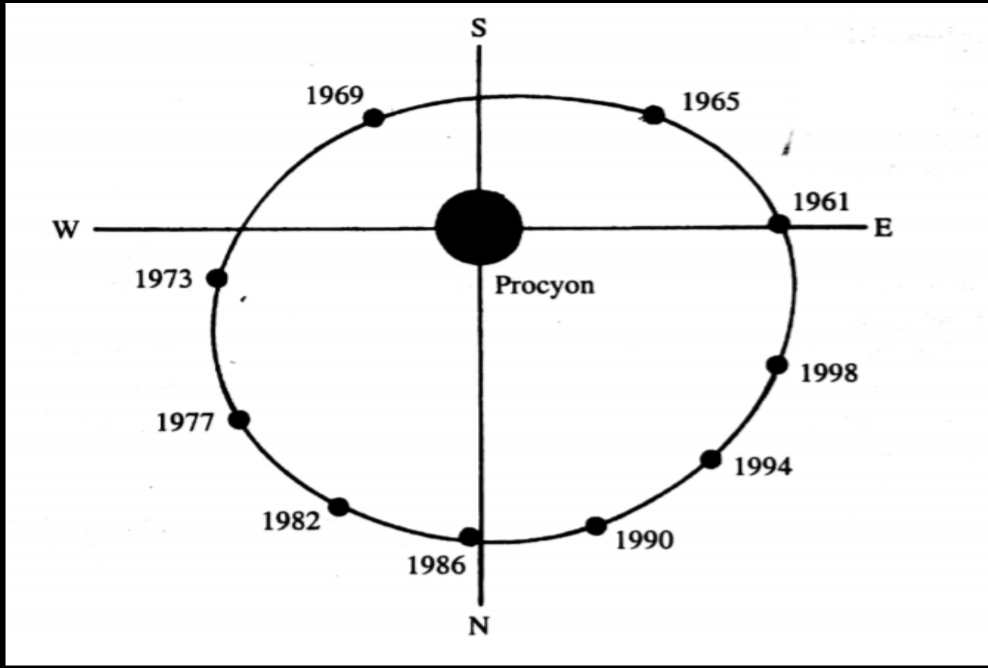
MASSES OF STARS :

Two stars revolving around each other form a binary system. Fortunately, a large fraction of stars are in binary systems and therefore their masses can be determined. Binary stars can be of three kinds :

- Visual binary stars
- Spectroscopic binary stars
- Eclipsing binary stars:

Visual binary stars :

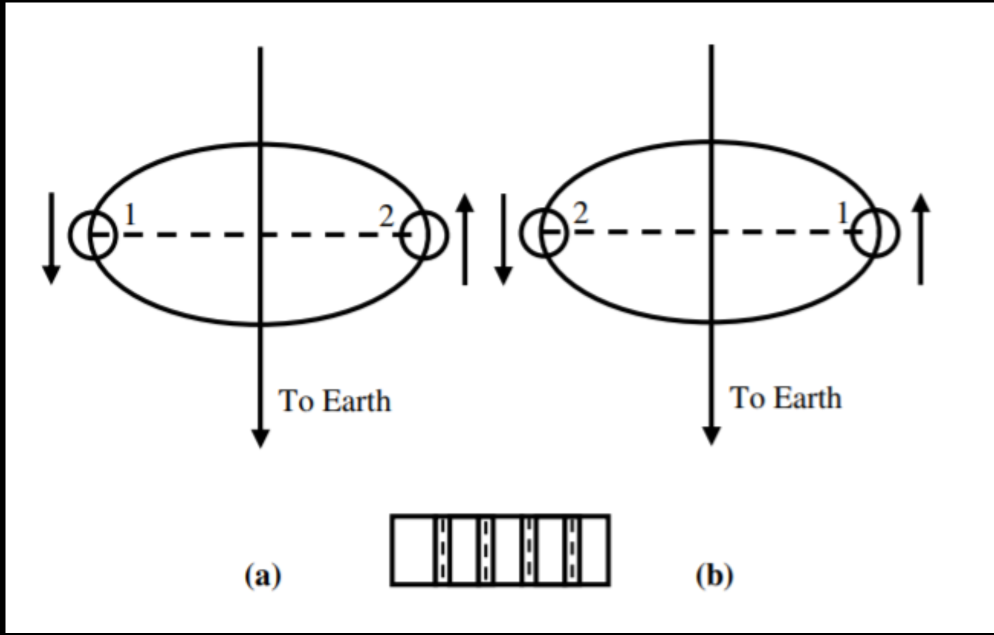
- Can be seen moving around each other with the help of a telescope.
- If they are of comparable mass they can be seen to be moving around their common centre of mass in elliptic orbits .
- However, if one is much more massive than the other, then the less massive star executes an elliptic orbit around the more massive star.



Orbit of visually binary stars

Spectroscopic binary stars :

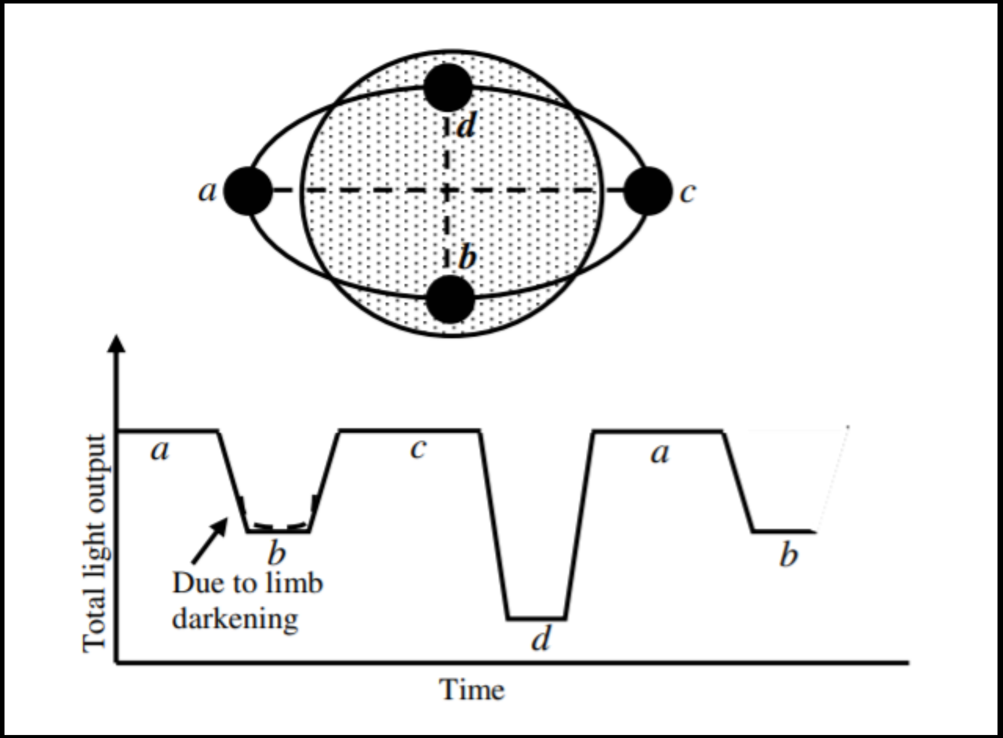
- Binary nature revealed by the oscillating lines of their spectra.



spectroscopic binary stars

Eclipsing binary stars :

If the orbits of two stars are such that the stars pass in front of each other as seen by an observer.



Eclipsing binary stars

Now how do we determine the mass ?

suppose suppose M_1 and M_2 are the masses of the two stars and a is the distance between them, then we can write Kepler's third law as:

$$\frac{GP^2}{4\pi r^2}\left(M_1 + M_2\right) = a^3$$

where P is the period of the binary system and G is the constant of gravitation. This relation gives us the combined mass of the two stars.

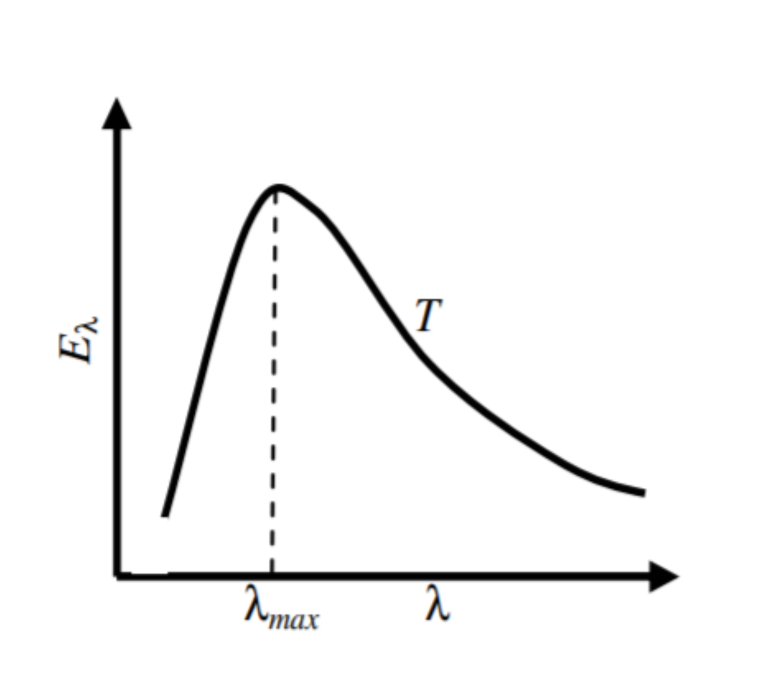
However, if the motion of both the stars around the common centre of mass can be observed, then we have :

$$M_1 a_1 = M_2 a_2$$

where a_1 and a_2 are distances from the centre of mass. Then both these equations allow us to estimate the masses of both the stars.

STELLAR TEMPERATURE :

- The temperature of a star can be determined by looking at its spectrum or color.
- The graph below shows the variation of radiant flux (F_λ) for different wavelengths (λ).



is quite similar to the one obtained for a black body at a certain temperature.

So, assuming the star to be radiating as a black body, it is possible to fit in a Planck's curve to the observed data at temperature **T.**

$$\lambda_{max} T = 0.29 cm\ K$$

Such a temperature is termed as surface temperature**,** T_s .

the effective temperature of a star corresponds to the one obtained using Stefan-Boltzman law, i.e.,

$$F = \sigma T_e^{4}$$

Stellar Parameters	Range
Mass	$0.1 - 100\ M_{\Theta}$
Radius	$0.01^* - 1000\ R_{\Theta}$
Luminosity	$10^{-5} - 10^{5}\ L_{\Theta}$
Surface Temperature	3000 – 50,000 K

Range of Stellar Parameters

We can find various empirical relationships among different stellar parameters, e.g., mass, radius, luminosity, effective temperatures, etc.

Observations show that the luminosity of stars depends on their mass. We find that the larger the mass of a star, the more luminous it is. For most stars, the mass and luminosity are related as :

$$\frac{L}{L_{\Theta}} = \left(\frac{M}{M_{\Theta}}\right)^{3.5}$$

THANK YOU !!!