



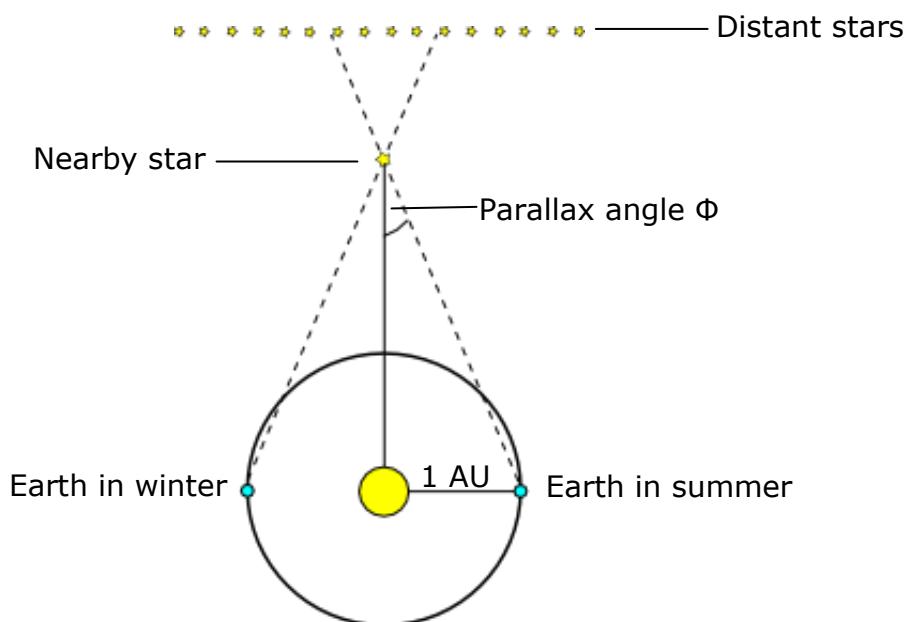
Lesson 3: Calculating distances to stars

What you need to know:

1. How the parallax can be used to calculate the distance to nearby stars.
2. How arc seconds can be used to calculate distances to stars.
3. The difference between brightness and luminosity.

Everybody knows that stars are very far away, but how can we calculate the distance to stars? Well if a star is 'nearby', meaning around 10 light years away, then we can use a method called the **trigonometric parallax**.

As the Earth moves around the Sun stars that are near to the Earth will appear to move when compared to stars that are very far away. This can be seen in the diagram below.



You can see that it is possible to draw a right angled triangle with the Earth, Sun and the star which we are looking at as the corners of the triangle. This means that it is possible to calculate the distance to the star using trigonometry. The **parallax angle**, which is the angle used in the trigonometric equation, is half the angle the star has been observed to move in six months, for example between winter and summer. The distance between the Earth and the Sun is called an **Astronomical unit (AU)**. Therefore, since we know the distance between the Earth and the Sun and the parallax angle, we can use the mathematic rule SOH CAH TOA to calculate the distance to the star.



In your exam you may be asked how the parallax can be used to calculate the distance to nearby stars.





Parallax angles are very small and so it is not possible to measure them in normal degrees, instead we measure parallax angles in terms of **arc seconds** (**or seconds of arcs**). As you will know, there are 360° in a circle, and if we take a single degree then it can be split into 60 smaller parts called arc minutes. Each arc minute can be split into 60 smaller sections called arc seconds.

$$1^\circ = 60 \text{ arc minutes.}$$

$$1 \text{ arc minute} = 60 \text{ arc seconds}$$

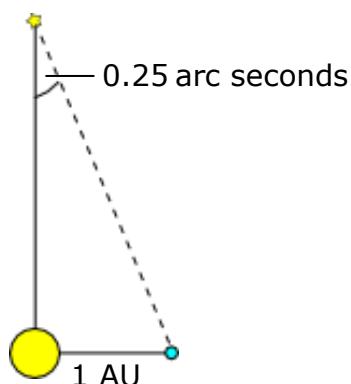
$$1^\circ = 60 \text{ arc minutes} \times 60 \text{ arc seconds}$$

$$1^\circ = 3600 \text{ arc seconds}$$

This means that **1 arc second is equal to $1/3600$ of a degree** and this means it is far easier to describe the parallax angles in terms of arc seconds.

$$\text{Angle in degrees} = (1/3600) \times \text{angle in arc seconds}$$

So, if a star has a parallax angle of 0.25 arc seconds, what is its distance in km?



Firstly we need to convert the parallax angle from arc seconds into degrees:

$$\text{Angle in degrees} = (1/3600) \times \text{angle in arc seconds}$$

$$\text{Angle in degrees} = (1/3600) \times 0.25$$

$$\text{Angle in degrees} = 6.9 \times 10^{-4}$$

Next, we need to find the distance between the Earth and the star, the hypotenuse in the triangle. Since we have the parallax angle and the opposite length, the distance between the Earth and the Sun, we can use the trigonometric rule:

$$\sin \Phi = \text{Opposite}/\text{Hypotenuse}$$

$$\sin (6.9 \times 10^{-4}) = 1\text{AU}/\text{Distance to star}$$

$$\text{Distance to star} = 1\text{AU}/\sin (6.9 \times 10^{-4})$$

$$\text{Distance to star} = 825059 \text{ AU}$$



However, we need to find the answer in km, so we need to convert the distance from AU into km.

$$1 \text{ AU} = 150,000,000 \text{ km}$$

$$\text{Distance to star} = 825059 \text{ AU} \times 150,000,000 \text{ km}$$

$$\text{Distance to star} = 1.24 \times 10^{14} \text{ km}$$

 In your exam you may be asked to state what an arc second is. You may also be asked to calculate the distance to a star using the parallax angle measured in arc seconds. 

The distance to stars is usually very large and so it is not practical to state the distances in metres or even kilometres, instead astronomers use a distance called a **parsec**. One parsec is the distance from the Earth to a star when the star has a parallax angle of 1 arc second. It is possible to calculate the distance in parsecs from the parallax angle using the equation:

$$\text{Distance in Parsecs} = 1/\text{parallax angle}$$

For example if a star has a parallax angle of 0.25 arc seconds:

$$\text{Distance in parsecs} = 1/0.25$$

$$\text{Distance} = 4 \text{ parsecs}$$

If the star has a parallax angle of 0.5 arc seconds, then the star will be at a distance of:

$$\text{Distance in parsecs} = 1/0.5$$

$$\text{Distance} = 2 \text{ parsecs}$$

 In your exam you may be asked to calculate the distance to a star in parsecs from a given parallax angle or vice versa. 

The distances to stars can't always be calculated from the parallax method. If the star is very far away, then the **brightness** of the star can be used to estimate the distance to the star. It is a rather simple principle; if a star is close by then it will appear bright, and if the star is far away it will appear dim. This method was first proposed by the Dutch astronomer, Christiaan Huygens.

This method only works if all stars are the same, but this is not always the case, as there are big stars, small stars, cool stars and hot stars. This means that each star will emit a different amount of energy, and this is called the **luminosity**. The luminosity of a star depends upon:

1. **Temperature**: The hotter the star the more energy it will emit



2. **Size:** The bigger the star, the more surface the star has to emit energy over.

This means that the **observed brightness** of a star depends upon:

1. How far the star is from the Earth.
2. The star's luminosity.



In your exam you may be asked how brightness can be used to calculate the distance to stars. You may also be asked to explain luminosity and observed brightness.



Recap:

1. The trigonometric parallax can be used to calculate the distance to nearby stars.
2. The parallax angle is the angle that a star is observed to make, compared to the background stars, due to the movement of the Earth around the Sun.
3. A star that has a parallax angle of 1 arc second has a distance of 1 parsec.
4. Distance in parsecs = $1 / \text{arc seconds}$.
5. The brightness of a star can be used to calculate the distance to stars.
6. The luminosity of a star depends upon the temperature and size of the star.