

Investigating the maths inside:

Stargazing with the SKA

Activity 5

Stars and parallax:   
Measuring the unmeasurable



How far is the nearest star (Proxima Centauri) from the earth?

How do astronomers measure distances in space?

What units do astronomers use?

### Measuring the unknown

Find a really tall object or an object somewhere in the distance. How tall the is it? How far away is it?

What methods did you use? Did any of the methods involve trigonometry?

### Parallax

The method that astronomers use to measure distances to nearby stars uses trigonometry and is called **parallax**.

It is possible to demonstrate this technique for judging distances with a simple experiment.

Hold your index finger in front of your eyes. Close your left eye, and note where your finger appears to be with respect to the background. Open your left eye and close your right eye, and now note where your finger appears to be with respect to the background. It appears to have moved, or made an apparent shift.



To use this method in space is more difficult. However, because the distance between the earth and the sun is known accurately it is possible to use this to find the distances to nearby stars.

In January, the Earth is on one side of the Sun (consider this the ‘left eye’ position), and 6 months later, in July, the Earth is on the other side of the Sun (the ‘right eye’ position). The distance between the Earth’s position in January and its position in July is twice the distance between the Earth and the Sun. When you observe a nearby star in January, and then again in July, the background stars will have changed by an amount that can be measured by a powerful telescope.

|  |
| --- |
| **Angle measures**  1 revolution = 360o (degrees)  1° (degree) = 60' (minutes) and 1’ (minute) = 1/60° (degree)  1' (minute) = 60" (seconds) and 1” (second) = 1/60’ (minute) = 1/3600° (degree)  1c (radians) =  (degrees) and 1° (degree) = π/180 c (radian) |

Using trigonometry, (tan θ = side opposite/side adjacent) we can calculate the lengths of the sides of a right-angled triangle. We have a right angle (from the Sun to the star) if we use half of the measured angle.

The distance to the star (d), the angle by which the star appears to have moved (θ), and the distance between the Earth and the Sun (b) are related in the following way:



We call the angle  the ‘parallax’ (*P*) of the star.

The distance from the Earth to the Sun (*b*) *=* 149 597 870 700 metres = 149 597 870 km (1.50  108)

Complete the table of tangents using your calculator or by setting up an Excel Spreadsheet

|  |  |
| --- | --- |
| Angle | Tangent |
| 45° |  |
| 1° (1 degree) |  |
| 1’ (1 minute) |  |
| 1’’ (1 second) |  |



# Using parallax

1. If the parallax angle is 1" and distance of the Earth from the Sun is 1.496  108 km, use trigonometry to find the distance of the star from the Sun.

Find the distance of the star from Earth in kilometres.

Why do you think astronomers only find the distance between the star and the Sun and do not worry about finding the distance between the star and Earth?

1. The nearest star to Earth, Proxima Centauri, undergoes a shift of 1.5 arcseconds in apparent position every 6 months. (Note: 1 second = 1 arcsecond)

Calculate its distance from the Sun in kilometres.

1. The next nearest neighbour to the Sun beyond the Alpha Centauri system is called Barnard’s Star. Its parallax is 0.55".

Calculate its distance from the Sun in kilometres.

# Astronomers’ measures

Parallax angles are incredibly small (1 arcsecond = th of a degree). The distances considered are very large.

The unit of measurement for distance that astronomers use is called the **parsec** (pc). This comes directly from the measurement of parallax for stars, because 1 parsec is the distance to a star with a **par**allax angle of 1 arc**sec**ond. Parsec is an abbreviation for **parallax arcsecond**.

In addition, astronomers refer to the distance between the Earth and the Sun as 1 AU, called the Astronomical Unit.

Why do you think they did this?

Another unit that astronomers use for distance is the light-year, which is the distance light travels in one year. These two measurements, parsecs and light years, are similar.

1. Determine 1 parsec in light years, AUs and kilometres. then complete the following table.

|  |  |  |  |
| --- | --- | --- | --- |
| Parcsecs | Light years | Astronomical Units | Kilometres |
| 1 |  |  |  |
|  | 1 |  |  |
|  |  | 1 |  |

Given the use of parsecs rather than conventional measurements like kilometres, for any parallax angle given in arcseconds, the distance to that star in parsecs (abbreviated pc) is simply



or 

For example, if you have a star with a parallax of 0.5 arcseconds:

The distance of the star from the sun parsecs.

1. A star has moved 0.5 seconds between photos. Find the distance of the star away from the sun (in parsecs) if the two photos were taken six months apart.

Check your answer using trigonometry.

1. The first star to have its parallax measured was 61 Cygni. In 1838, Friedrich Bessel calculated its parallax to be 0.314 arcsec.

What is the distance to 61 Cygni based on Bessel's measurement in parsecs?

What is the distance in light years?

1. Find the distance of Proxima Centauri (the nearest star to Earth other than the Sun) from the sun, whose parallax is 0.7687,

Does this check with your answer in question 2?

1. Computing the uncertainty in distance to a star based on its parallax can be a difficult. Consider the case of Joe and the star Rigel. Joe measures a parallax half-angle of **θ = 0.004 arcsec** to Rigel. He estimates the uncertainty in his measurement to be **0.003 arcsec**. In other words, the parallax could be as large as 0.007 arcsec, or as small as 0.001 arcsec.
2. What is the distance to Rigel, if Joe's measurement is exactly correct?
3. Will a parallax of 0.001 or a parallax of 0.007 give the greatest distance?
4. What is the distance to Rigel, if the error in Joe's measurement is –0.003 arcsec?
5. What is the distance to Rigel, if the error in Joe's measurement is +0.003 arcsec?
6. What is the actual distance to Rigel? Do we know exactly what the distance is?
7. Sirius has a parallax angle of 0.38 seconds of arc.

Find the distance of Sirius from the Sun in light years.

1. Why can’t astronomers use simultaneous observations from different parts of Earth’s surface to determine stellar distances?

# Challenge

Show how the astronomical formula  is equivalent to the trigonometric formula .

(Hint: For very small angles in radians ).

Discuss why astronomers use the astronomical formula and the associated units.