CHAPTER 23

Astrometry: finding the distance to stars

Careful measurement of a celestial object's position in the sky (astrometry) may be used to determine its distance

Measuring distances in space

23.1

- ***Define the terms parallax, parsec and light-year***
- ***Explain how trigonometric parallax can be used to determine the distance to stars***

Due to the vast distances in space, the conventional unit of length, the metre, requires the use of powers of 10, which make the number too large to readily comprehend. Consequently, alternative length units that measure much larger distances are used by astronomers and in general language. The **light-year** is the distance light travels in one Earth year. A brief calculation yields this distance in metres:

$$\begin{aligned} 1 \text{ l.y.} &= \text{speed of light} \times 1 \text{ Earth year} \\ &= 3.0 \times 10^{8} \text{ m s}^{-1} \times 365 \times 24 \times 60 \times 60 \text{ s} \\ &= 9.5 \times 10^{15} \text{ m} \end{aligned}$$

The light-year is used for popular astronomy articles and discussions; however, another unit, the **parsec**, is also used by amateur and professional astronomers. One parsec is 3.26 light-years. The word parsec is derived from its origins: 'par' from '**parallax**'; 'sec' from 'arcseconds', or one second of a degree of arc. Parallax is the way in which a closer object seems to move against a distant background when the observing position moves. Holding one's finger out at arm's length when looking at a more distant background and then closing one eye at a time causes an apparent movement of your finger against the background. Relatively close stars exhibit a similar (but much smaller) apparent movement against the background of distant stars and galaxies as the Earth orbits the Sun. This movement is too small to be noticed except by careful comparison of photographic or photometric records taken at different times of the year. A simple formula is applied to calculate the distance to the star once its parallax angle is measured:

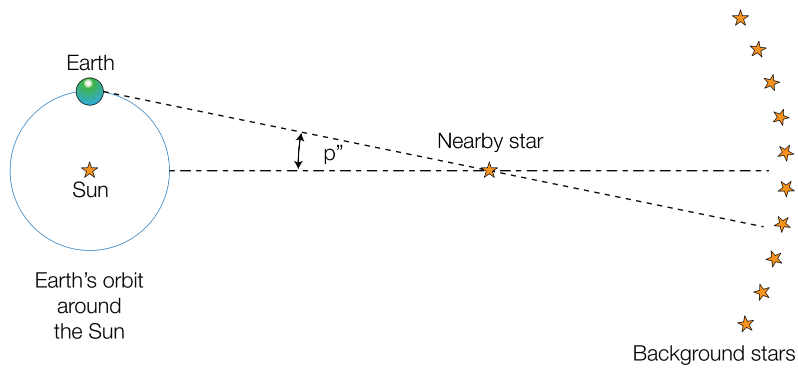


Figure 23.1 The geometry of trigonometric parallax measurement

$$d = \frac{1}{p''}$$

Where:

d = the distance in parsecs

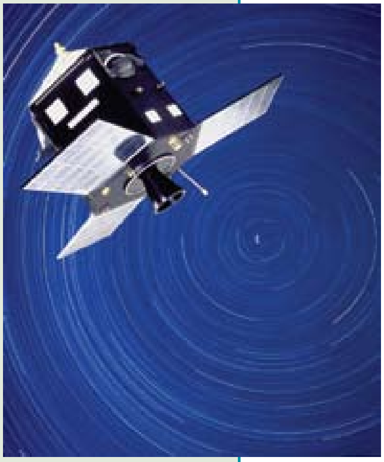
p'' = the star's parallax angle in arcseconds

The parallax angle used to determine distance in parsecs is *half* the maximum parallax angle that a star may exhibit over a six-month period.

23.2 The limitations of trigonometric parallax

■ *Discuss the limitations of trigonometric parallax measurements*

Figure 23.2 The Hipparcos Observatory



Limits in the resolution of telescopes due to seeing (the blurring effect of the Earth's atmosphere) make parallax angle measurements of less than 0.01" (arcsecs) not possible with errors of less than 10%. This places an effective limit of 100 parsecs (as $d = 1/p''$) on the distance measuring capability of trigonometric parallax from ground-based observers. Other factors, such as the refraction of starlight by the atmosphere, may cause errors in the position of the star that must be corrected. As trigonometric parallax is used by astronomers to calibrate other distance measuring techniques, this is quite a severe limitation. As our Milky Way galaxy has a diameter of approximately 45,000 parsecs, either better resolution or a different but equally reliable distance measuring technique is required. In the late 1980s and early 1990s, the Hipparcos Observatory, unaffected by seeing, was able to measure the parallax angles of around 2.5 million stars with a precision of less than 0.001", increasing the distance measured to the furthest stars to about 1000 parsecs.

WWW→ **USEFUL WEBSITE**

This website shows real data animation from the Hipparcos database:
http://www.rssd.esa.int/Hipparcos/apps/ShowMotion.html

The European Space Agency is planning to launch the Gaia Observatory into Earth orbit in late 2010 or 2011. The twin 1.45 m diameter telescopes on board are expected to be able to measure the distance to over one billion stars to within an accuracy of 20% at a distance of about 10,000 parsecs. Its observations are expected to be 100 times more accurate than Hipparcos. The Gaia Observatory will be placed in an orbit around the Sun at L2, a point in space directly on the opposite side of the Earth to the Sun where it will be protected from Sun's glare and follow Earth in its orbit.

L2 is a Lagrange point, one of several where a spacecraft will remain stationary with respect to the Earth due to the balancing of gravity. In the case of L2, the gravity of the Earth and the Sun combine so that the Gaia Observatory will orbit the Sun with the Earth, but with a slightly larger orbital radius.

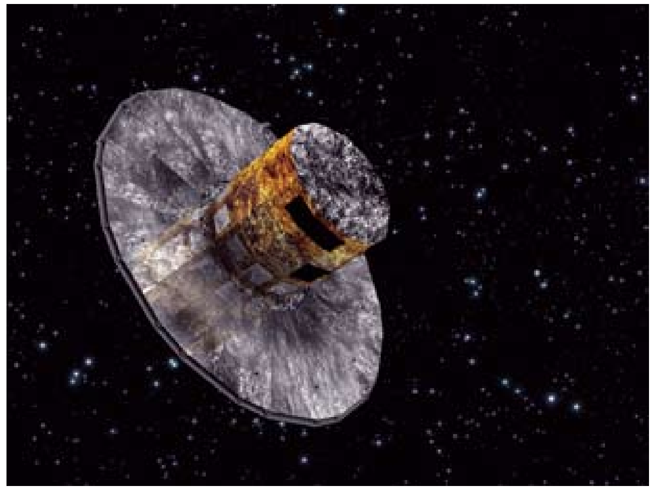


Figure 23.3 The Gaia Observatory, planned for launch in 2010 or 2011

USEFUL WEBSITES

**The European Space Agency website for the Gaia mission:
http://www.esa.int/esaSC/120377_index_0_m.html**

**NASA's website for the SIM (Space Interferometry Mission) for proposed launch in 2009:
http://planetquest.jpl.nasa.gov/SIM/sim_facts.cfm**

WWW

- ***Solving problems: Using trigonometric parallax to find the distance to a star***
- ***Solve problems and analyse information to calculate the distance to a star given its trigonometric parallax using:***

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

Sample question 1

What is the calculated distance to the sixth star in the Hipparcos catalogue which has a parallax angle of 18.80 milli arcseconds?

Sample answer

Using $d = \dfrac{1}{p''}$: $\quad d = \dfrac{1}{18.80 \times 10^{-3}}$

$$= 53.19 \text{ parsec}$$

Sample question 2

The red giant star Betelgeuse is 130 parsecs away. Could the distance to Betelgeuse be calculated using ground-based parallax methods?

Sample answer

The parallax angle of Betelgeuse is found using: $d = \dfrac{1}{p}$,

$$\text{so that } p = \frac{1}{d}$$

$$= \frac{1}{130}$$

$$= 0.0077 \text{ arc secs}$$

As this parallax angle is less than 0.01", it is too small to be measured with acceptable accuracy from ground-based instruments.

The relative limits of ground-based and space-based trigonometric parallax

SECONDARY SOURCE INVESTIGATION

PFAs

H1, H5

PHYSICS SKILLS

H12.3A, B, C, D
H12.4B

- ***Gather and process information to determine the relative limits to trigonometric parallax distance determinations using recent ground-based and space-based telescopes***

WWW→

USEFUL WEBSITE

This website from the Australia Telescope Outreach and Education facility gives useful information. In summary, it states that ground-based observations are limited to distances of about 40 parsecs due to atmospheric distortion, while the Hipparcos satellite was capable of determining distances to about 1000 parsecs:
http://outreach.atnf.csiro.au/education/senior/astrophysics/parallaxlimits.html

Other useful information can be found by using search terms such as 'parallax limitations' in your favourite search engine.

CHAPTER REVISION QUESTIONS

1. Outline the process of trigonometric parallax.
2. Describe the effect on the measurements made using trigonometric parallax if the radius of Earth's orbit were doubled.
3. Explain why the Hipparcos Observatory has been so successful in measuring the distance to stars.
4. Compare the distances between one a.u. (astronomical unit), one light-year and one parsec by using a scale diagram.
5. Describe the benefits of launching observatories that will have improved resolution when making trigonometric parallax measurements.
6. 'A light-year and a parsec will be different for a civilisation on a planet in another solar system.' Why would this be so?
7. Find the distance in parsecs to a star with a parallax angle of:
   (a) 0.05 arcsecs
   (b) 0.230"
   (c) 0.008 +/– 0.002"

SR

Answers to chapter revision questions