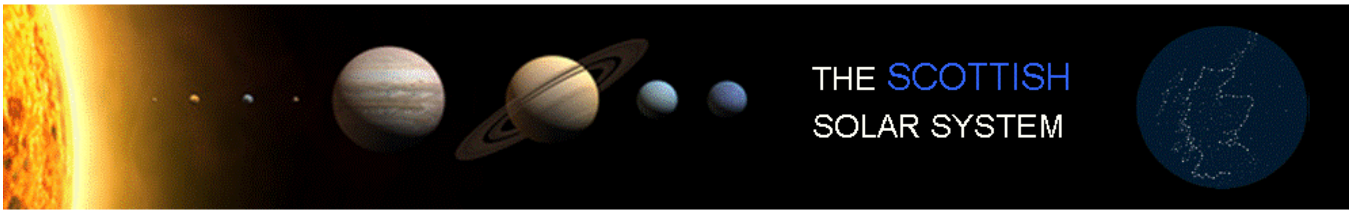


International Year of Astronomy 2009

Schools Projects for Autumn Moonwatch

Project 3: Measuring the distance of the Moon

Suitable for advanced primary and secondary ages, and for naked-eye or telescopic observing.

The Moon is our closest neighbour in space: it lies at an average distance of 384,400 km, or about 60 Earth radii, from the Earth (see Fig. 1). If the Earth were a basketball, roughly 10 inches in diameter, the Moon would be the size of a tennis ball, 25 feet away.

Fig 1. The Earth – Moon system, shown to the correct scale

Because the Moon is comparatively close to us (the Sun, for example, is nearly 400 times further away, see also Project 2, and the *next* nearest star system, Alpha Centauri, is more than 100 million times further than the Moon) it displays what astronomers call **parallax**.

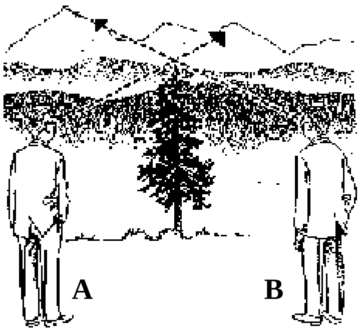


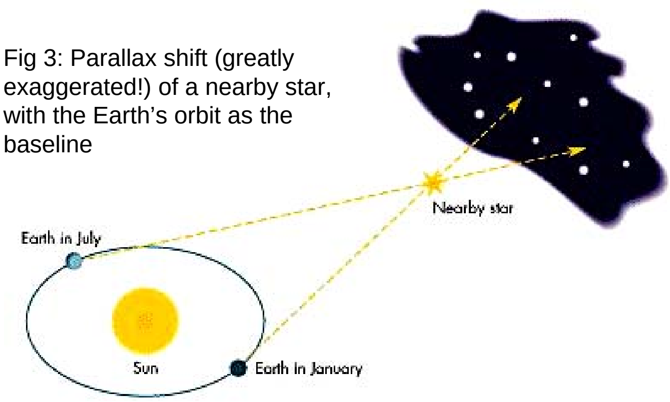
Fig 2: The effect of parallax. A and B line up the tree with different hills because they see it along different lines of sight

The effect of parallax can be easily seen in everyday life if, for example, we hold up a finger and look at it first through our left and then our right eye. The finger seems to 'line up' with different far away objects because from each eye we are looking past our finger along a different line of sight. Figure 2 shows a similar effect for two observers lining up a nearby treetop with their view of distant hills.

It was the *absence* of parallax displayed by the stars that undermined Aristarchus' theory that the Earth orbited the Sun, and not the other way around (see also Project 2).

It was recognised that, if the Earth *did* go around the Sun, then the apparent position of a nearby star should change, with respect to more distant stars, between e.g. January and July.

Fig 3: Parallax shift (greatly exaggerated!) of a nearby star, with the Earth's orbit as the baseline



University of Glasgow

In fact the stars *do* show exactly this parallax shift, but it is tiny – because they are so far away! The nearest star (after the Sun) shows an annual parallax shift, over six months, of about a two thousandth of the width of the Full Moon (about half a degree across). It is no surprise, then, that ancient Greek astronomers couldn't measure such a tiny shift, and it took until the middle of the 19th century before the first parallax shifts were detected.

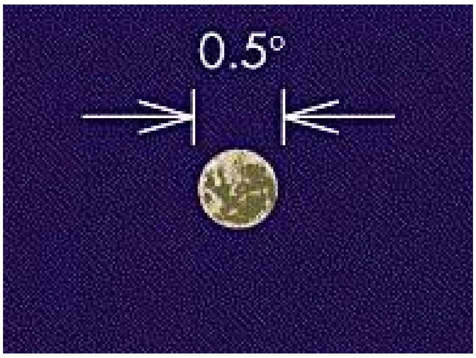


Fig 4: Angular size of the Full Moon

In the case of the Moon, on the other hand, because it is so much closer to us, the parallax shift is much easier to see. In fact we can measure it using only the diameter of the Earth itself (as opposed to the Earth's orbit) as our baseline.

In particular, the position of the Moon, when viewed from different places on the surface of the Earth, appears to change slightly compared to the positions of bright background stars.

Figure 5 shows an example of this lunar parallax from March 1988, when the Moon was close in the sky to the Pleiades cluster, in the constellation of Taurus the Bull.

We can see that the Moon's apparent position clearly shifts, when viewed from opposite points on the equator or from the North and South Pole of the Earth.

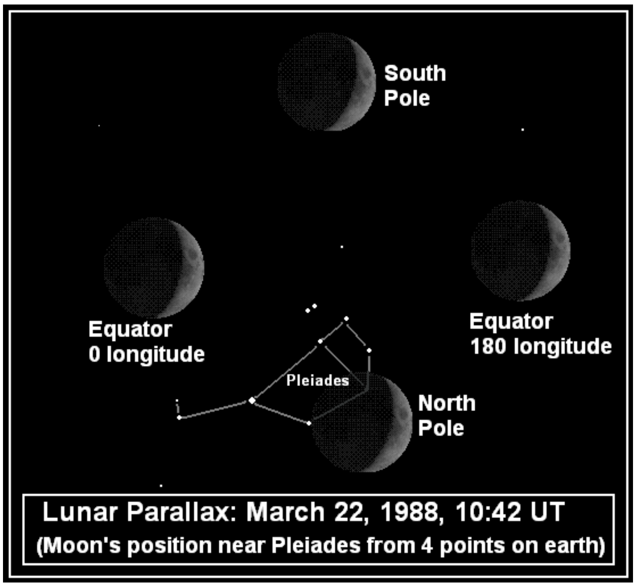


Fig 5: Parallax shift of the Moon, when viewed from the Earth's equator and poles.

In the autumn and winter of 2009-10, there will be (clouds permitting!) some good opportunities to measure the lunar parallax, from well-separated locations on the Earth. By measuring the **parallax angle** – the amount by which the Moon appears to shift in position – we can work out how far away the Moon is (at least provided we also know how big the Earth is!)

The further away the Moon is, the smaller its parallax shift.

For example, on **30th November 2009** at 6pm local time, the Moon will be visible low in the sky from **Perth, Scotland**.

At exactly the same time (2am local time on **1st December 2009**) the Moon will also be visible from **Perth, Western Australia**.

Figures 6 and 7 show the apparent position of the Moon at these times, and observed from these two locations. Note the angular distance between the Moon and the stars of the Pleiades at this time. The numbers given refer to the angle between the centre of the Moon and the Pleiades star Electra, which is identified in the inset of each figure.

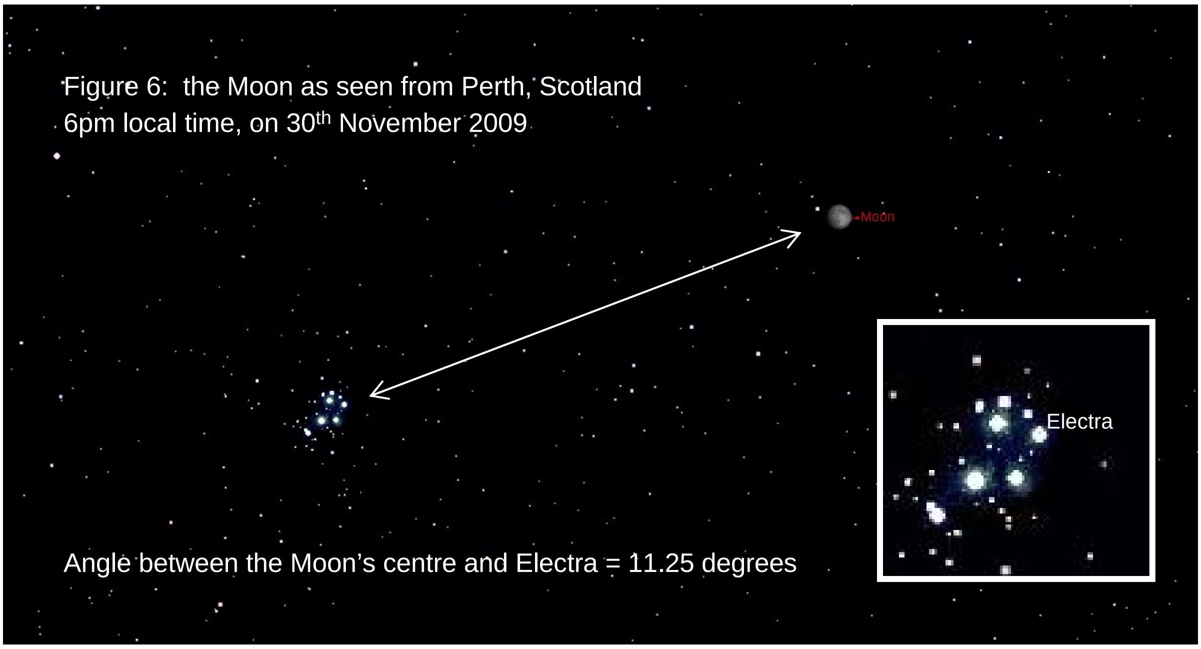


Figure 6: the Moon as seen from Perth, Scotland
6pm local time, on 30th November 2009

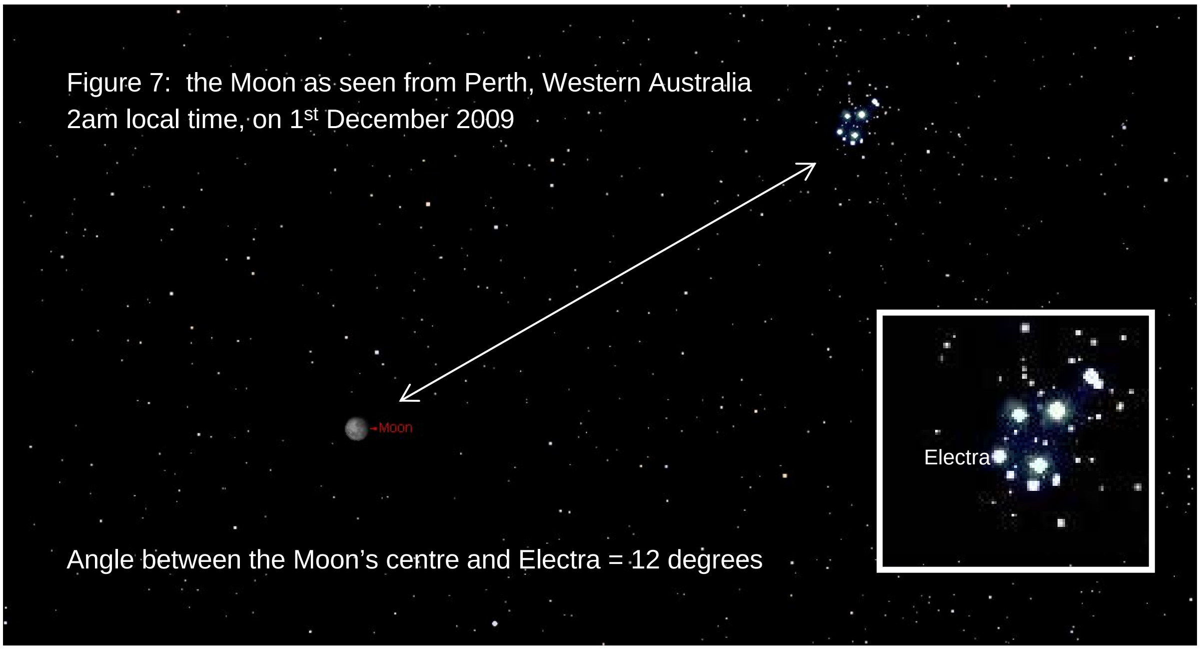


Figure 7: the Moon as seen from Perth, Western Australia
2am local time, on 1st December 2009

So we see that the angular separation between the Moon and the Pleiades is different in Perth, Scotland and Perth, Western Australia by about **0.75 degrees**, or about one and a half times the width of the Full Moon. We can convert this angle into a distance to the Moon, provided we also know the distance between Scotland and Western Australia.

We plan to observe the Moon simultaneously in Scotland and Australia, on 30th November / 1st December 2009, and to carry out our own measurement of the Earth – Moon distance. If any Scottish or Western Australian schools (particularly those in or around the two Perths!) are interested in participating in this exciting project, please contact us as soon as possible at:

scottishsolarsystem@astro.gla.ac.uk

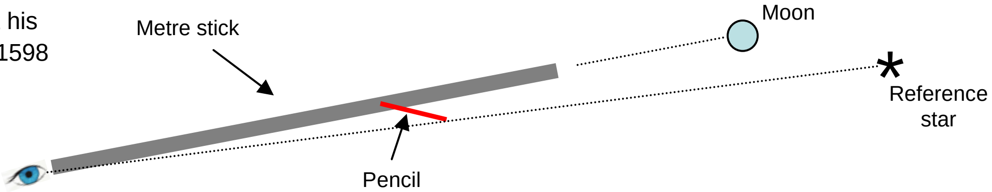
Measuring the angular separation of the Moon and Electra (or other suitable reference stars) should be possible *without* the aid of a telescope.   In fact, because the Moon will be close to Full Moon on November 30th, it will be very bright – making it in any case difficult to see through a telescope stars which are near to it on the sky.

Depending on the sky conditions, it may be necessary to use reference stars further from the Moon than the Pleiades, such as Capella or Aldebaran.

Fig 8. Tycho Brahe, at work with a giant quadrant at his Uraniborg Observatory, 1598

Measuring angles between objects in the sky can be done quite precisely, even with the naked eye. Astronomers like **Tycho Brahe** could measure the positions of stars to a small fraction of a degree before the invention of the telescope, using a device called a **quadrant**, which was rather like a giant protractor. You can build your own quadrant using e.g. a metre stick and a pencil

- First line up the metre stick with the Moon's edge, and hold the end of the metre stick up to your eye.
- Position the pencil along the metre stick, so that its tip appears to just cover the reference star on the sky.



Some high school trigonometry then gives a good estimate of the angle:

$$\tan(\text{angle}) = \frac{\text{length of pencil}}{\text{distance along metre stick}}$$

Even if the weather is unkind on 30th November / 1st December, there will be other opportunities to observe the Moon simultaneously from across the Earth, later in the autumn / winter of 2009-10. Check out the Scottish Solar System website for details.

Also, another (closely related) project, which can be carried out from a single location, involves tracking the *changes* in the Moon's distance from the Earth.

The German astronomer Johannes Kepler, who was a contemporary of Galileo, also made a number of crucial contributions to our understanding of the motions of the planets.

In 1609 and 1619 Kepler published his **Three laws of Planetary Motion**.

The first of these laws abandoned the 2000 year-old idea, due to the Greeks, that the orbits of the planets were built from circles. Instead, the orbits are actually ellipses – flattened circles – With the Sun at one focus of the ellipse.

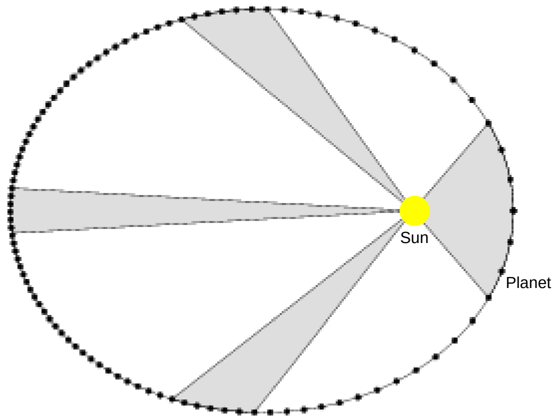


Fig 9. Illustration of Kepler's First and Second Laws of planetary motion.

Kepler's Second Law states that as a Planet follows its elliptical orbit around the Sun, it sweeps out equal areas in equal times – which means that a planet will move faster when it is closer to the Sun.

The extent to which an orbit is flattened is measured by its eccentricity. A perfectly circular orbit is a special case of an ellipse with eccentricity zero. The orbit of a comet, on the other hand, which spends most of its time very far from the Sun, is an example of an ellipse with eccentricity close to one (the maximum value possible).

The orbit of the Moon around the Earth (or more correctly the orbit of the Moon and the Earth around each other) is also slightly elliptical – with a eccentricity of about 5%. This is enough to cause a marked difference in the apparent size of the Moon when it is at its furthest from and nearest to the Earth. (These points are referred to as Apogee and Perigee).

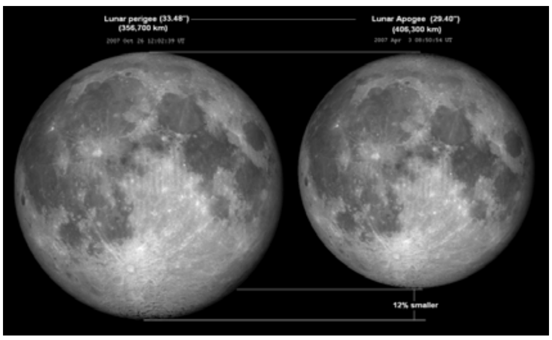


Fig 10. Change in the apparent size of the Moon between perigee and apogee, due to the eccentricity of the Moon's orbit.

Using a metre-stick quadrant, or some other device for measuring angles, keep a record of the size of The Full Moon throughout the autumn and winter of 2009-10.

Can you detect the eccentricity of the Moon's orbit?...