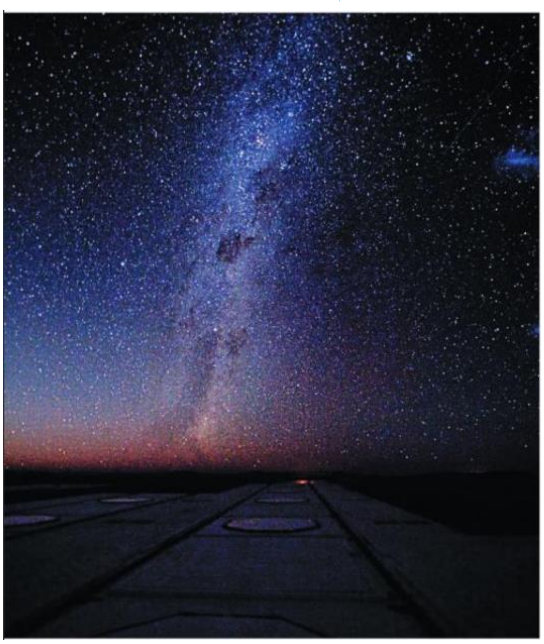
Surveying the Universe

Gauging the Universe, understanding its spatial structure, is essential to unravelling the cosmic history, even though our senses do not perceive the third dimension – distance. Yet knowing a star's distance is crucial for determining its size, intrinsic brightness, dynamics and evolution.

Measuring the distances to the Moon and the Sun has been a primary goal of astronomy. In 1751, Lalande and Lacaille used the parallax method to measure the distance to the Moon. Today, the Earth-Moon distance is known with millimetre precision, achieved by boucing laser beams from the Earth off reflectors placed on our satellite's surface. Today, the average Earth-Sun distance, on which the astronomical unit (AU) was historically based, is measured with a precision of a few ten kilometres. Initially, planetary distances were determined using the parallax method. Now, radar echo techniques, similar to lunar laser ranging, provide precision measurements within a few kilometres.

The celestial vault

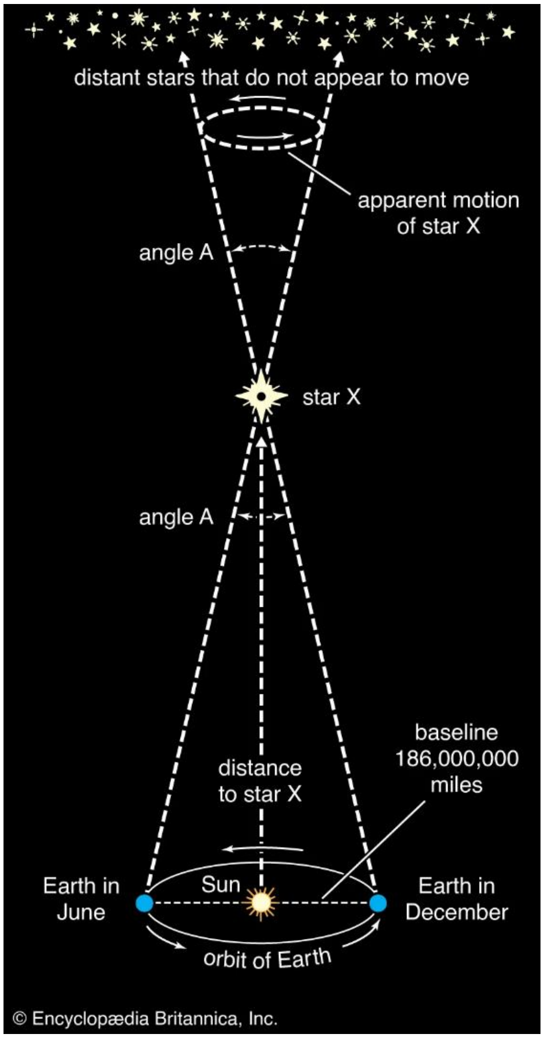
A portion of the sky observed from the VLT site in Chile: the celestial vault is composed of stars located at varied distances.



Credit: ESO/H. Heyer

The nearest stars are incomparably farther than the outermost reaches of our Solar System. The parallax method, based on Earth's orbit and implemented by the European satellite Hipparcos, has enabled scientists to measure the distances to over 2 milllion stars. Proxima Centauri, the closest to the Sun, has a parallax of 0.769 arcseconds, corresponding to a distance of 38 trillion kilometres. Rather than traditional distance units, astronomers prefer to express these distances in light-years (ly) or parsecs (pc). Proxima Centauri is thus 4.243 ly or 1.301 pc away.

Beyond a few hundred parsecs, parallax measurements are no longer accurate enough and astronomers have to resort to other methods. The



most common is the standard candle method. It relies on the fact that the brightness of a luminous object is inversely proportional to the square of its distance. Astronomers can determine the distance to a star by comparing its apparent brightness to that of a reference star of the same type whose distance is known via the parallax method, and, therefore, its absolute brightness.

On the scale of distant intergalactic space, candles are scarce (apart from thermonuclear supernovae), so astronomers prefer to use redshift – the shift of spectral lines towards longer wavelengths that is observed in distant galaxies. As demonstrated by Hubble in 1929 when he discovered the expansion of the Universe, the redshift increases with the distance as measured by the standard candle method.

Errors in the Earth-Sun distance affect the parallax measurement of stars' distances. Uncertainties in the parallax method impact the measured distances of reference stars, thereby distorting the standard candle method, which in turn distorts redshift measurements. Given this accumulation of methods, as we probe further into the Universe, errors (confidence intervals) associated with these distances increase, compounded by uncertainties arising from our often imperfect knowledge of the physical processes involved.

The parallax method

A star observed from two opposite points in Earth's orbit (i.e. six months apart) appears to shift slightly relative to the background stars forming the celestial vault. The half-angle corresponding to this apparent motion is called the parallax. Since the diameter of Earth's orbit is known (299 million km), it is possible to calculate the distance to the star by measuring the parallax.

The redshift method

From bottom to top, the spectra of increasingly distant galaxies are shown. The redshift of the absorption lines observed in distant galaxies is used to estimate their distance within the framework of the Universe's expansion theory.