How are distances of astronomical objects measured?

ASTRONOMERS often quote gigantic figures for the distances and masses of heavenly bodies. How do they arrive at such numbers? There has been a steady progress gradually over the centuries, and more rapidly in the last few decades, in the art of astronomical measurements.

For example, how does one measure the distance to the Moon, our nearest heavenly neighbour? The technique employed here is the same as that used by surveyors in measuring distances and heights on the Earth. The principle is illus-

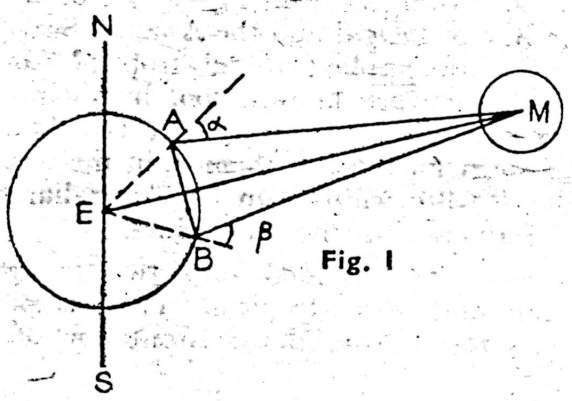


Fig. 1

trated in Fig. 1. Two observers, A and B, placed on the same longitude look at the Moon, M, at the same time and measure the angles α and β which the Moon makes with their respective zeniths (zenith is the vertical direction at the point of observation). The rest is all trigonometry! Knowing the locations of A and B on the Earth's surface, the triangle MAB can be constructed with the data. Then a simple calculation determines the distances MA, MB and ME. The last length is the distance of the Moon from the centre of the Earth. This is called "the method of trigonometric parallax".

Can the same method be used for the Sun? In principle, yes; but, in practice, no. One difficulty is that the angle, analogous to AMB for the Moon, will be about 400 times smaller for the Sun. This reduces the accuracy of the method. Also, the Sun's edge is not sharp enough to make measurements. A better method makes use of the distance of a nearby planet P (Fig. 2). The distance EP can be measured by the method used for the Moon. Then Kepler's third law of planetary motion is made use of.

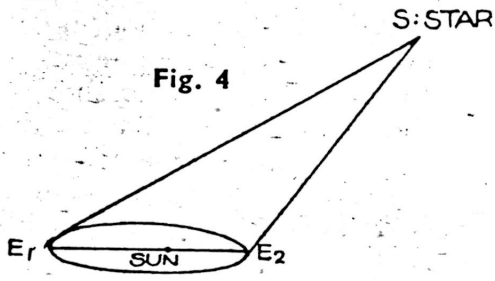


Fig. 4

The law states that the cube of the mean distance of the planet from the Sun is proportional to the square of the planet-year, the time taken by the planet to go once round the Sun. For example, a Venus-year is approximately 224·7 days, while the Earth-year is 365·25 days. Therefore, by this law the ratio of the *cubes* of the mean distances of Venus and Earth from the Sun will be $(224{\cdot}7)^2/(365{\cdot}25)^2$. This gives the ratio of their distances from the Sun as 0·723.

Similarly, the law gives the *ratio* of the distances SP and SE. Knowing the angle PES at the time of measurement, the Earth-Sun distance, SE, can be determined.

A modern method uses the radar technique illustrated in Fig 3. A powerful radar signal is bounced from the surface of the planet Venus during inferior conjunction — when it is nearest to us and approximately in the direction of the Sun. If the signal takes a total time T to come back, the distance travelled by it to Venus and back is simply, $c \times T$, where the signal speed is known to be equal to the speed of light, c. This gives, $VE = \frac{1}{2}cT$. Again, Kepler's third law gives the ratio of SE to SV. Therefore, SE can be determined.

What about the distances of other stars in our Galaxy? They are measured by the same trigonometric surveying method used for the Moon, but with one difference: the star in question is not observed from two points on the Earth, but from two diametrically opposite positions on the Earth's orbit around the Sun (Fig. 4).

The further the star is from the Sun, the smaller would be the angle E_1SE_2. The limitations on measuring extremely small angles, therefore, limit the parallax method to distances of the order of a thousand light years or so. (A light year is about ten million million kilo-

Fig. 2

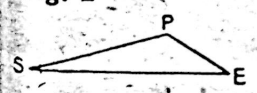
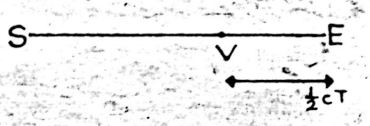


Fig. 3



metres.) Great as this distance is, it is not enough to cover the depths of our own Galaxy — the Milky Way System — let alone the universe beyond it!

What is the method, then, of measuring the distances of very remote stars in the Milky Way? Luckily, certain stars show daily variations in their light output. The mean output from these so-called variable stars is found to be remarkably constant from one star to another. Such stars can be chosen as 'standard candles'. Imagine two such stars, one located at a distance of 500 light years (measured by the parallax method) while a similar one appears 100 times fainter. This implies that the latter is ten times further way, at a distance of 5,000 light years. The principle behind the measurement is the well-known inverse square law of illumination.

The variable star technique is also used to measure the distances of nearby galaxies like the Andromeda. However, the method fails for more remote galaxies, for we have to treat the whole galaxy as a standard candle! Unfortunately, the light output varies considerably from galaxy to galaxy. It is, therefore, possible to mistake a nearby weakly emitting galaxy for a remote strongly emitting one. The possibility of such an error can be reduced to some extent by a choice of galaxies of the same class. For example, Allan Sandage of the Hale Observatories, USA, has discovered that the brightest members of the clusters of galaxies have approximately the same light output.

What other methods, if any, are used for measuring extragalactic distances? A simple method is provided by Hubble's law. This states that the red shift of a galaxy is proportional to its distance. The red shift is the fraction by which the wavelength of a spectral line in the spectrum of the galaxy is increased as compared to that on the Earth. For example, the wavelength of the hydrogen line Hβ is 4861Å. If the same line is found in the galactic spectrum at 5833·2Å, the galaxy has a red shift of 0·2. By Hubble's law, this galaxy must be located at a distance of approximately 3,600,000,000 light years! A galaxy with a red shift of 0·1 would be at half this distance.

It is not yet clear what is the farthest distance one can measure. This is because we do not yet know what form Hubble's law takes at moderately large red shifts. Indeed, several factors intervene to make its interpretation ambiguous at red shifts greater than, say, 0·2. Hence, although a galaxy with a red shift as

high as 0·637 and quasi-stellar objects with red shifts up to 3·53 are known, it is not yet possible to put a clear distance label on them. By and large, we can only say that our telescopes can probe the universe up to distances of the order of ten thousand million light years.

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