Distances and Motions

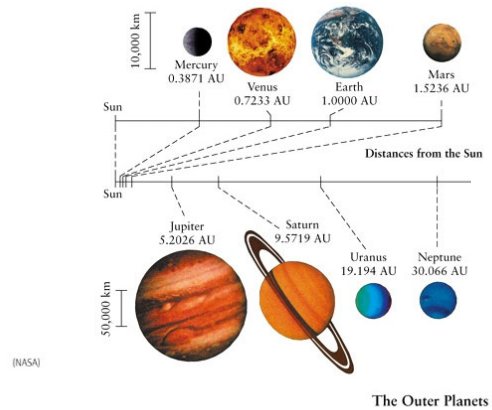
Questions

How far away is the nearest star?

What is the furthest object we can see?

It does not look like it, but are stars moving?

Terrestrial & Jovian Planets



Determining the AU

Today, the Earth-Sun distance (= 1 AU) is known to high precision from radar measurements of the distances to the planets. (The relative scale of the planet distances was known from Copernicus and Kepler.) Radar observations of Venus began in 1958.

Since we know the distance to each planet in AUs, measurement of the time required by radar signals to travel from the Earth to a planet and back establishes the size of the AU in km.

c = 299,792.458 km/s **(3.0 x 10^5 km/s)**

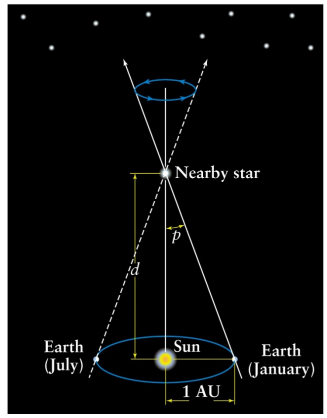
AU = 149,597,870.7 km **(1.5 x 10^8 km)**

Triangulation and Parallax

To reach the nearest stars, we use the **orbit** of the Earth as a baseline and the technique of **triangulation**.

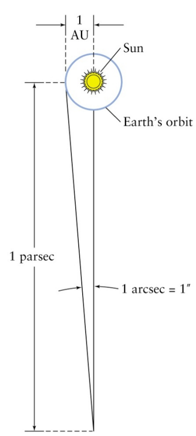
The greater the **angular change** (i.e., **parallax**), the nearer the star.

Parallax Interactive



Universe, Geller, Freedman, and Kaufmann

Parsec



Definition

Baseline = 1 AU
Angle α = 1 arcsec

d = 206,265 AU
= 1 parsec
= 1 pc

Distance

$$d = 1 / p'' \text{ (pc)}$$

$$d = 206{,}265 / p'' \text{ (AU)}$$

where p" is in arcseconds

Example: if p'' = 0.11 arcseconds
then d = **9.1 pc**
or = 9.1 x 206,265 = **1.9 x 10^6 AU**

Early Measurements of Distances

Stars are so distant that the parallaxes of even the nearest ones are too small to be measured with the techniques available to Aristotle. William Herschel tried to measured parallaxes, but instead got orbits of binary stars.

Parallaxes were eventually detected, but even the nearest star shows a total annual displacement of only about 1.5 arcsec. The first observation of parallax of a star is usually credited to the German astronomer Friedrich Bessel (in 1838).

Light Year

Light travels at a speed of about 186,000 miles per second (300,000 km/s). So in one second, light has traveled 186,000 miles; in two seconds it has gone 372,000 miles.

Let the clock run for one entire year, and the light will have traveled 5.9×10^{12} miles (9.5×10^{12} km) or **63,240 AU**.

The distance that light travels in one year is defined as 1 **Light Year**.

The nearest star is about four light years away (distance), or you can say that the light emitted by this star takes four years (time) to travel the expanse of space between it and us.

Units of Distance

Astronomical Unit (AU)	Distance from the Earth to the Sun
Parsec (pc)	Parallax of 1 arcsecond
Light Year (ly)	Distance light travels in one year

$$d = 1 / p'' \text{ (pc)}$$

$$d = 206{,}265 / p'' \text{ (AU)}$$

$$1 \text{ pc} = 3.26 \text{ ly}$$

The Nearest Stars

Alpha Centauri d = 1.3 pc

or p" = 0.76 arcsec

Sirius d = 2.6 pc

Parallaxes measured from the Earth are accurate to 100 pc of the Sun.

There are ~5000 stars in this region of space, but most are invisible to the naked eye.

Gaia Observations

p" = 0.000020 arcsec

= 0.020 milli-arcsec

d = 50,000 pc

Gaia is a ESA space observatory launched in 2013. The spacecraft is designed for **astrometry**: measuring the positions, distances and motions of stars with unprecedented precision.

Its mission is to determine the position, parallax, and proper motion of 1 billion stars with an accuracy of about 20 micro-arcseconds (μas).

Radial Velocity

The **radial velocity** is the speed that a star has as it approaches or recedes from the Sun. It is counted as **positive** if it is **moving away** from the Sun.

$$\Delta \lambda / \lambda = v / c = (\lambda_{obs} - \lambda) / \lambda$$

$$v = c \; \Delta\lambda / \lambda$$

Since the motion of either the star or the observer (or both) produces a Doppler shift in the spectral lines, a knowledge of the radial velocity alone does not enable one to decide which one "is doing the moving". What is really measured is the speed with which the distance between the star and Sun is increasing or decreasing.

Radial Velocity

Example: $\lambda_{obs} = 500.5$ nm $\lambda = 500.0$ nm

$$\Delta\lambda / \lambda = v / c = (\lambda_{obs} - \lambda) / \lambda$$

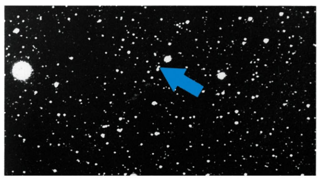
$$(\lambda_{obs} - \lambda) / \lambda = (500.5 - 500.0) / 500.0 = 0.001$$

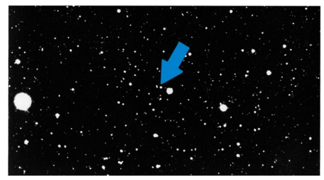
$$v = 0.001\, c = 300 \text{ km/s}$$

Proper Motion

The **proper motion** is the rate at which a star's apparent position on the sky changes. With respect to "background" stars, the motions of a few nearby stars can be observed.

μ is in arcseconds / year


August 24, 1894


May 30, 1916

Barnard's Star changes its position by 10.25 arcsec per year.

Proper Motion of Barnard's Star

Tangential Velocity

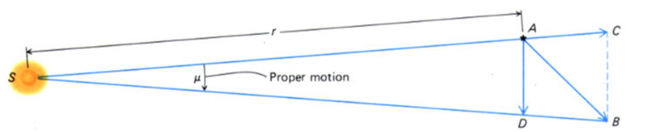


FIGURE 21.7 Relationship of proper motion, radial velocity (*AC*), and tangential velocity (*AD*).

Radial velocity is the motion of a star along the line of sight, while proper motion is the angular motion produced by the star's **motion across the sky**.

Whereas the radial velocity is known in km/s and is independent of distance, the proper motion of a star does not give the star's actual speed.

The latter is called the **tangential velocity**.

Abell's Exploration of the Universe, Morrison, Wolff, & Fraknoi

Tangential Velocity

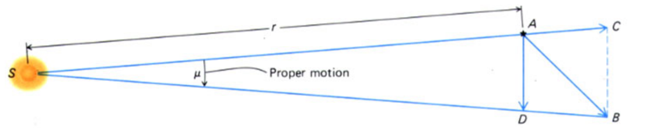


FIGURE 21.7 Relationship of proper motion, radial velocity (*AC*), and tangential velocity (*AD*).

To calculate the **tangential velocity**, one must know the **proper motion** and **distance** (or parallax).

$$\mathbf{T = 4.74\,\mu\,d = 4.74\,\mu\,/\,p''} \quad \text{(km/s)}$$

where μ is in arcsec/year, **d** is in parsecs, and p" is in arcsec.

Abell's Exploration of the Universe, Morrison, Wolff, & Fraknoi

Tangential Velocity

Example: **d = 25 pc** **μ = 0.5 arcsec/yr**

$$\mathbf{T = 4.74\,\mu\,d = 4.74\,\mu\,/\,p'' \quad (km/s)}$$

$$\mathbf{T = 4.74\,(0.5)\,(25) = 59\ km/s}$$

where μ is in arcsec/year, **d** is in parsecs, and **p"** is in arcsec.

Space Velocity

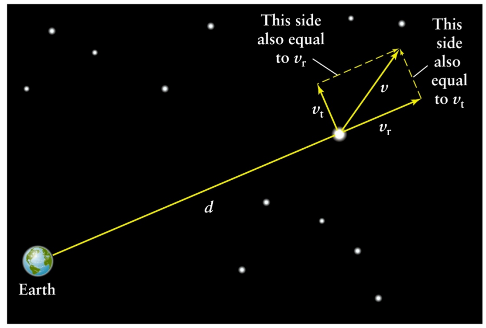
The total **Space Velocity** is

$$V^2 = V_R^2 + V_T^2$$

$$V^2 = (300)^2 + (59)^2$$

$$V = \text{sqrt}(\ 93481\ )$$

$$V = 306 \text{ km/s}$$



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