What Is a Parsec?

ONE OF THE MOST NOTORIOUSLY challenging aspects of astronomy is determining distances to faraway celestial objects. There's no way for us to take a cosmic tape measure and trot along to a nearby star to see how far it is, as we would, say, if we're laying out the track for a 100-meter race. There is no direct way to determine distances to the planets, stars, and galaxies — if we want to know how far they are we need to do use an indirect method. (See page 12 of the October 2022 issue of *Sky & Telescope* for a whole article on celestial distance determination and its challenges.)

We may very well ask why it's important to know how far away things are. Well, to begin with, it's natural curiosity to want to know our place in the universe. Scientists have been tackling this issue all the way back to Aristarchus of Samos, who in the 3rd century BC tried to figure out the sizes and relative distances between Earth, the Moon, and the Sun. He used observations of the first- and last-quarter Moon combined with some geometry and math to determine that the Sun was 19 times farther than the Moon. He was off by a lot (it's in fact some 390 times more distant), but his approach was revolutionary.

When we look up at the night sky, some stars look brighter than others. But are they *truly* brighter, or is it just a consequence of how close they are? If all stars were of the same intrinsic brightness, then we might assume that dimmer stars are farther than brighter ones. But that's not the case — a luminous star far away might look as bright as a dimmer star nearby. And, it was only once we understood that stars lie at different distances that we began to better understand their true nature.

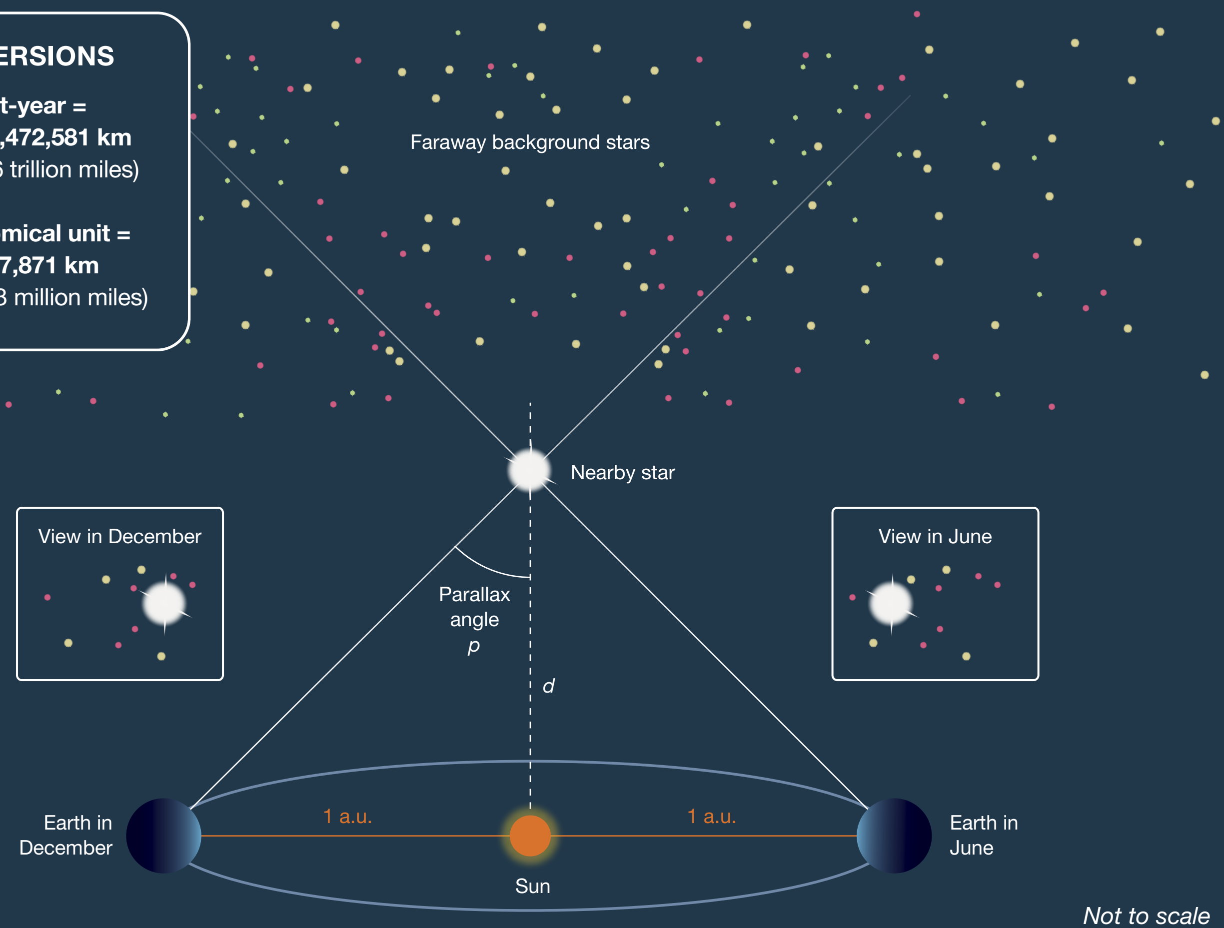
As a reader of this magazine, you'll notice that we largely express distances to celestial objects in terms of *light-years*, i.e., the distance that light travels in one year. We also use the *astronomical unit* (abbreviated to a.u.), which is the average distance between Earth and the Sun. However, there's another unit of distance that we sometimes bandy about (and which is favored by professional astronomers) and that is the *parsec*.

Before we discuss the parsec, let's first touch upon *parallax*.

CONVERSIONS

1 light-year = 9,460,730,472,581 km
(or nearly 6 trillion miles)

1 astronomical unit = 149,597,871 km
(or nearly 93 million miles)



BEATRIZ INGLESSIS / S&T; SOURCE: ESA

From Parallax . . .

How did we first start understanding how far away celestial objects are in the local universe? Quite straightforwardly, in fact — expanding on a familiar phenomenon, *stereoscopic vision*.

If you're standing, say, in a field of sunflowers and looking at a distant copse, you'll notice that if you close one eye, open it, then close the other eye that the image of the clump of trees doesn't move very much against the more distant, stationary landscape. But now crouch down in the field and do the same with a nearby sunflower. You'll notice the sunflower *appears* to move way more (than the copse) against the background. The apparent shift of a foreground object against a backdrop farther away is known as *parallax*.

This phenomenon happens because our eyes are side by side — they give us the perspective we need to gauge distances. But it only works for relatively nearby objects — our eyes are too close together for the effect to be useful for larger distances. In other words, the *baseline* of our two eyes is very short.

But imagine if we could extend the distance between our eyes. Obviously we can't do that, but we do have a very useful tool to hand: Earth's orbit around the Sun. If we substitute telescopes for our eyes and point them at a celestial target at six-month intervals, we have a baseline that's equivalent to twice the distance of Earth from the Sun. Now we're talking!

. . . to Parsec

To measure parallax, we need Earth orbiting the Sun (check), a target (pick your favorite object), distant background stars (there are many!), and a telescope with which to make the measurements. Follow along with the diagram on the previous page.

Observations of a nearby object taken six months apart will show that its position shifts against faraway background stars (that appear stationary) by a certain angle, the stellar parallax. Half that angle helps us measure the star's distance from the Sun using a very simple equation.

The diagram shows a right triangle with adjacent sides formed by the distance between Earth and the Sun as well as the distance between the Sun and the target star. The parallax is the angle between them. So, applying high-school trigonometry we have:

$$\tan(p) = \frac{1 \text{ a.u.}}{d}$$

(Remember that? The tangent of an angle equals the opposite side divided by the adjacent side.)

Rearranging yields:

$$d = \frac{1 \text{ a.u.}}{\tan(p)}$$

For very small angles, the formula simplifies to:

$$d = 1/p$$

If an object's position on the sky appears to shift by an angle, *p*, of 1 arcsecond when observed over a baseline of 1 a.u., then the object lies at a distance, *d*, of 206,265 a.u., or 3.26 light-years. And voilà, we have the definition and value for the parsec — which is a portmanteau for *parallax of one second*.

The table lists parallaxes (in milliarcseconds) and distances (in both parsecs and light-years) for a selection of stars. Note that we're indeed dealing with very small angles — and that the smaller the angle, the farther the object.

Star	*p* (mas)	*d* (pc)	*d* (l-y)
Sirius	379	2.66	8.68
Pollux	96.5	10.4	33.9
Castor	63.3	15.8	51.5
Aldebaran	48.9	20.4	66.5
Betelgeuse	6.55	153	499
Rigel	3.78	265	864

So long as we can measure the parallactic angle of an object, we can derive its distance. And, until we can find a way to stretch out our cosmic tape measure, our parallax estimates will have to do! ■

The subdivisions of degrees we call *minutes of arc* (or *arcminutes*) and *seconds of arc* (or *arcseconds*) date back to the ancient Babylonian astronomers and are units for measuring celestial angles. Nothing to do with the minutes and seconds that we use to keep time, they nevertheless break down in a similar fashion:

1 degree (°) = 60 arcminutes (′)   1 arcminute = 60 arcseconds (″)   So...   1° = 3,600″