EXAMPLE 33–6 ESTIMATE **Distance to a star using parallax.** Estimate the distance D to a star if the angle θ in Fig. 33–11 is measured to be 89.99994°.

APPROACH From trigonometry, $\tan\phi = d/D$ in Fig. 33–11. The Sun–Earth distance is $d = 1.5 \times 10^8$ km.

SOLUTION The angle $\phi = 90° - 89.99994° = 0.00006°$, or about 1.0×10^{-6} radians. We can use $\tan\phi \approx \phi$ since ϕ is very small. We solve for D in $\tan\phi = d/D$. The distance D to the star is

$$D = \frac{d}{\tan\phi} \approx \frac{d}{\phi} = \frac{1.5 \times 10^8\,\text{km}}{1.0 \times 10^{-6}\,\text{rad}} = 1.5 \times 10^{14}\,\text{km},$$

or about 15 ly.

Distances to stars are often specified in terms of parallax angle given in seconds of arc: 1 second (1″) is $\frac{1}{60}$ of a minute (′) of arc, which is $\frac{1}{60}$ of a degree, so $1'' = \frac{1}{3600}$ of a degree. The distance is then specified in parsecs (meaning *par*allax angle in *sec*onds of arc), where the **parsec** (pc) is defined as $1/\phi$ with ϕ in seconds. In Example 33–6, $\phi = (6 \times 10^{-5})°(3600) = 0.22''$ of arc, so we would say the star is at a distance of $1/0.22'' = 4.5$ pc. It is easy to show that the parsec is given by

Parsec (unit)

$$\begin{aligned} 1\,\text{pc} &= 3.26\,\text{ly} \\ &= (3.26\,\text{ly})(9.46 \times 10^{15}\,\text{m/ly}) = 3.08 \times 10^{16}\,\text{m}. \end{aligned}$$

Parallax can be used to determine the distance to stars as far away as about 100 light-years (≈ 30 parsecs) from Earth, and from an orbiting satellite perhaps 5 to 10 times farther. Beyond that distance, parallax angles are too small to measure. For greater distances, more subtle techniques must be employed. We might compare the apparent brightnesses of two galaxies and use the inverse square law (intensity drops off as the square of the distance) to roughly estimate their relative distances. We can't expect this technique to be very precise because we don't expect all galaxies to have the same intrinsic luminosity. A perhaps better estimate assumes the brightest stars in all galaxies (or the brightest galaxies in galaxy clusters) are similar and have about the same absolute luminosity. Consequently, their *apparent* brightness would be a measure of how far away they were.

Another technique makes use of the H–R diagram. Measurement of a star's surface temperature (from its spectra) places it at a certain point (within 20%) on the H–R diagram, assuming it is a main-sequence star, and then its luminosity can be estimated off the vertical axis (Fig. 33–6). Its apparent brightness and Eq. 33–1 give its approximate distance; see Example 33–5.

Cepheid variables

A better estimate comes from comparing *variable stars*, such as *Cepheid variables* whose averaged intrinsic luminosity (varying in time) has been found to be correlated to their periods.

SNIa as standard candles

The largest distances are estimated by comparing the apparent brightnesses of type Ia supernovae (SNIa). Type Ia supernovae all have a similar origin (they collapse to a neutron star at 1.4 solar masses, as described on the previous page and Fig. 33–10), and their brief explosive burst of light is expected to be of nearly the same total luminosity. They are thus sometimes referred to as "standard candles."

Another important technique for estimating distance is from the "redshift" in the line spectra of elements and compounds. The redshift is related to the expansion of the universe, as discussed in Section 33–5. It is useful for objects further than 10^7 to 10^8 ly away.

As we look farther and farther away, the measurement techniques are less and less reliable, so there is more and more uncertainty in the measurements of large distances.