One way to estimate the age of the universe uses the Hubble parameter. With $H \approx 22\,\mathrm{km/s}$ per 10^6 light-years, the time required for the galaxies to arrive at their present separations would be approximately (starting with $v = d/t$ and using Hubble's law, Eq. 33–6),

$$t = \frac{d}{v} = \frac{d}{Hd} = \frac{1}{H} \approx \frac{(10^6\,\mathrm{ly})(0.95 \times 10^{13}\,\mathrm{km/ly})}{(22\,\mathrm{km/s})(3.16 \times 10^7\,\mathrm{s/yr})} \approx 13.7 \times 10^9\,\mathrm{yr},$$

or 13.7 billion years. The age of the universe calculated in this way is called the *characteristic expansion time* or "Hubble age." It is a rough estimate and assumes the rate of expansion of the universe was constant (which today we are quite sure is not true). Recent precise measurements (2003) give the age as $13.7 \times 10^9\,\mathrm{yr}$, in remarkable agreement with the rough Hubble age estimate.

Age of the universe

* Steady-State Model

Before discussing the Big Bang in detail, we mention one alternative to the Big Bang—the **steady-state model**—which assumed that the universe is infinitely old and on average looks the same now as it always has. (This assumed uniformity in time as well as space was called the *perfect cosmological principle*.) According to the steady-state model, no large-scale changes have taken place in the universe as a whole, particularly no Big Bang. To maintain this view in the face of the recession of galaxies away from each other, mass–energy conservation must be violated. That is, matter must be created continuously to maintain the assumption of uniformity. The rate of mass creation required is very small—about one nucleon per cubic meter every 10^9 years.

The steady-state model provided the Big Bang model with healthy competition in the mid-twentieth century. But the discovery of the cosmic microwave background radiation (next Section), as well as the observed expansion of the universe, has made the Big Bang model almost universally accepted.

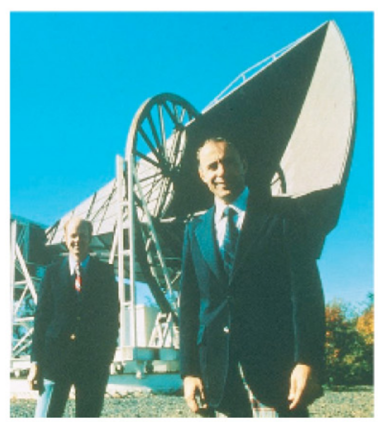
33–6 The Big Bang and the Cosmic Microwave Background

The expansion of the universe seems to suggest that typical objects in the universe were once much closer together than they are now. This is the basis for the idea that the universe began about 13.7 billion years ago as an expansion from a state of very high density and temperature known affectionately as the **Big Bang**.

The Big Bang

The Big Bang was not an explosion, because an explosion blows pieces out into the surrounding space. Instead, the Big Bang was the start of an expansion of space itself. The volume of the observable universe was very small at the start and has been expanding ever since. The initial tiny volume of extremely dense matter is not to be thought of as a concentrated mass in the midst of a much larger space around it. The initial tiny but dense volume *was* the universe—the entire universe. There wouldn't have been anything else. When we say that the universe was once smaller than it is now, we mean that the average separation between galaxies (or other objects) was less. Thus, it is the *size of the universe itself* that has increased since the Big Bang.

FIGURE 33–21 Robert Wilson (left) and Arno Penzias, and behind them their "horn antenna."



A major piece of evidence supporting the Big Bang is the **cosmic microwave background** radiation (or CMB) whose discovery came about as follows.

In 1964, Arno Penzias and Robert Wilson were experiencing difficulty with what they assumed to be background noise, or "static," in their radio telescope (a large antenna device for detecting radio waves from the heavens, Fig. 33–21). Eventually, they became convinced that it was real and that it was coming from outside our Galaxy. They made precise measurements at a wavelength $\lambda = 7.35\,\mathrm{cm}$, in the microwave region of the electromagnetic spectrum (Fig. 22–8). The intensity of this radiation was found initially not to vary by day or night or time of year, nor to depend on direction. It came from all directions in the universe with equal intensity, to a precision of better than 1%. It could only be concluded that this radiation came from the universe as a whole.

The 2.73-K cosmic microwave background radiation