To understand why, let us look at what a Big Bang might have been like. The temperature must have been extremely high at the start, so high that there could not have been any atoms in the very early stages of the universe. Instead, the universe would have consisted solely of radiation (photons) and a plasma of charged electrons and other elementary particles. The universe would have been opaque—the photons in a sense "trapped," traveling very short distances before being scattered again, primarily by electrons. Indeed, the details of the microwave background radiation is strong evidence that matter and radiation were once in equilibrium at a very high temperature. As the universe expanded, the energy spread out over an increasingly larger volume and the temperature dropped. Only when the temperature had fallen to about 3000 K, some 380,000 years later, could nuclei and electrons combine together as atoms. With the disappearance of free electrons, as they combined with nuclei to form atoms, the radiation would have been freed—**decoupled** from matter, we say. The universe became *transparent* because photons were now free to travel nearly unimpeded straight through the universe.

Photons decoupled

As the universe expanded, so too the wavelengths of the radiation lengthened (you might think of standing waves, Section 11–13), thus redshifting to longer wavelengths that correspond to lower temperature (recall Wien's law, $\lambda_P T$ = constant, Section 27–2), until they would have reached the 2.7-K background radiation we observe today.

* Looking Back toward the Big Bang—Lookback Time

Figure 33–24 shows our Earth point of view, looking out in all directions back toward the Big Bang and the brief (380,000 year long) period when radiation was trapped in the early plasma (yellow band). The time it takes light to reach us from an event (say 5×10^9 yr ago) is called its **lookback time**. The "close-up" insert in Fig. 33–24 shows a photon scattering repeatedly inside the plasma and then exiting the plasma in a straight line. No matter what direction we look, our view of the very early universe is blocked by this wall of plasma—we can see only as far as its surface, called the "surface of last scattering," but not into it. Wavelengths from there are redshifted by $z \approx 1000$. Time $\Delta t'$ in Fig. 33–24 is the lookback time (not real time that goes forward).

Lookback time

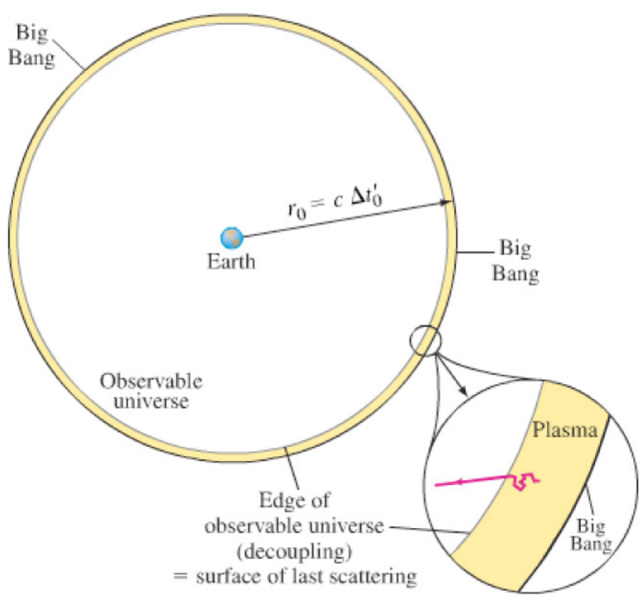

FIGURE 33–24 When we look out from the Earth, we look back in time. Any other observer in the universe would see the same thing. The farther an object is from us, the earlier in time the light we see left it. We cannot see quite as far as the Big Bang; we can see only as far as the "surface of last scattering," which represents the CMB. The blowup shows the earliest 380,000 years of the universe when it was opaque: a photon is shown scattering many times and then (at decoupling, 380,000 yr after the Big Bang) becoming free to travel in a straight line. If this photon wasn't heading our way when "liberated," many others were. Galaxies are not shown, but would be concentrated close to Earth in this diagram. *Note:* This diagram is not a normal map. Maps show a section of the world as might be seen all *at a given time*. This diagram shows space (like a map), but each point is *not* at the same time. The light coming from a point a distance r from Earth took a time $\Delta t' = r/c$ to reach Earth, and thus shows an event that took place long ago, a time $\Delta t' = r/c$ in the past, which we call its "lookback time." The Big Bang happened $\Delta t_0' = 13.7$ Gyr ago.