TABLE 33–1 Heavenly Distances

Object	Approx. Distance from Earth (ly)
Moon	4×10^{-8}
Sun	1.6×10^{-5}
Size of solar system (distance to Pluto)	6×10^{-4}
Nearest star (Proxima Centauri)	4.3
Center of our Galaxy	2.6×10^4
Nearest large galaxy	2.4×10^6
Farthest galaxies	10^{10}

of galaxies in each cluster. Furthermore, clusters themselves seem to be organized into even larger aggregates: clusters of clusters of galaxies, or **superclusters**. The farthest detectable galaxies are on the order of 10^{10} ly distant. See Table 33–1.

CONCEPTUAL EXAMPLE 33–2 **Looking back in time.** Astronomers often think of their telescopes as time machines, looking back toward the origin of the universe. How far back do they look?

RESPONSE The distance in light-years measures precisely how long in years the light has been traveling to reach us, so Table 33–1 tells us also how far back in time we are looking. For example, if we saw Proxima Centauri explode into a supernova today, then the event would have really occurred 4.3 years ago. The most distant galaxies, 10^{10} ly away, emitted the light we see now 10^{10} years ago; so what we see was how they were then, 10^{10} yr ago, close to the beginning of the universe.

EXERCISE A Suppose we could place a huge mirror 1 light-year away from us. What would we see in this mirror if it is facing us on Earth? When did it take place? (This might be called a "time machine.")

Besides the usual stars, clusters of stars, galaxies, and clusters and superclusters of galaxies, the universe contains a number of other interesting objects. Among these are stars known as *red giants*, *white dwarfs*, *neutron stars*, exploding stars called *novae* and *supernovae*, and *black holes* (very probably) whose gravity is so strong even light can not escape them. In addition, there is electromagnetic radiation that reaches the Earth but does not emanate from the bright pointlike objects we call stars: particularly important is the microwave background radiation that arrives nearly uniformly from all directions in the universe. We will discuss all these phenomena.

Finally, there are "active galactic nuclei" (AGN), which are very luminous pointlike sources of light in the centers of distant galaxies. The most dramatic examples of AGN are *quasars* ("quasistellar objects" or QSOs), which are so luminous that the surrounding starlight of the galaxy is drowned out. Their luminosity is thought to come from matter starting to fall into a giant black hole at a galaxy's center.

Quasar (QSO)

33–2 Stellar Evolution: The Birth and Death of Stars

The stars appear unchanging. Night after night the heavens reveal no significant variations. Indeed, on a human time scale, the vast majority of stars change very little (except for novae, supernovae, and certain variable stars). Although stars *seem* fixed in relation to each other, many move sufficiently for the motion to be detected. Speeds of stars relative to neighboring stars can be hundreds of km/s, but at their great distance from us, this motion is detectable only by careful measurement. Furthermore, there is a great range of brightness among stars. The differences in brightness are due to differences in the amount of light stars emit as well as to their different distances from us.

Luminosity and Brightness of Stars

A useful parameter for a star or galaxy is its **luminosity** (or "absolute luminosity"), L, by which we mean the total power radiated in watts. Also important is the **apparent brightness**, l, defined as the power crossing unit area at the Earth perpendicular to the path of the light. Given that energy is conserved, and ignoring any absorption in space, the total emitted power L when it reaches a distance d from the star will be spread over a sphere of surface area $4\pi d^2$. If d is the distance from the star to the Earth, then L must be equal to $4\pi d^2$ times l (power per unit area at Earth). That is,

$$l = \frac{L}{4\pi d^2}. \tag{33–1}$$