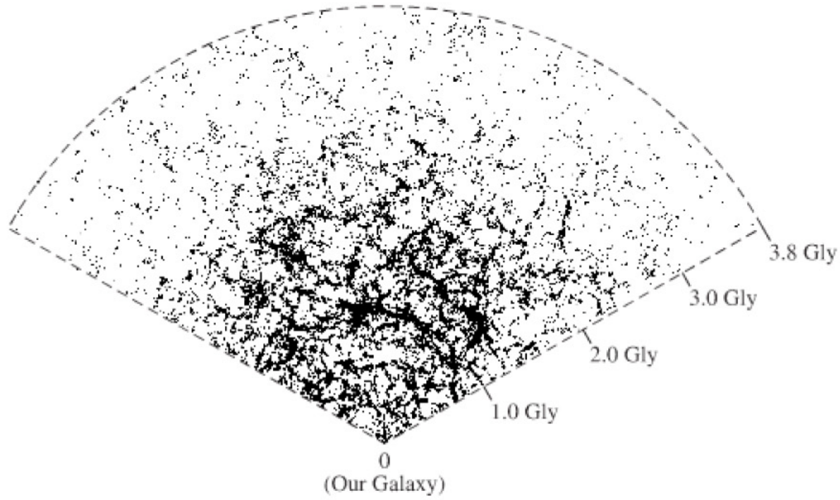


**FIGURE 33–27** Distribution of some 50,000 galaxies in a 2.5° slice through almost half of the sky above the equator, as measured by the Sloan Digital Sky Survey (SDSS). Each dot represents a galaxy. The distance from us is obtained from the redshift and Hubble's law, and is given in units of $10^9$ light-years (Gly). At greater distances, fewer galaxies are bright enough to be detected, thus resulting in an apparent thinning out of galaxies. The point 0 represents us, our observation point. Note the "walls" and "voids" of galaxies.

## 33–9 Large-Scale Structure of the Universe

The beautiful WMAP pictures of the sky (Fig. 33–23 and Chapter opening photo) show small but significant inhomogeneities in the temperature of the CMB. These anisotropies reflect compressions and expansions in the primordial plasma just before decoupling, from which stars, galaxies, and clusters of galaxies formed. Analysis of the irregularities in WMAP by mammoth computer simulations predict the distribution of clusters of galaxies and superclusters of galaxies very similar to what is seen today (Fig. 33–27). These simulations are very successful if they contain dark energy and dark matter; and the dark matter needs to be *cold* (slow speed—think of Eq. 13–8, $\frac{1}{2}m\bar{v}^2 = \frac{3}{2}kT$ where $T$ is temperature), rather than "hot" dark matter such as neutrinos which move at or very near the speed of light. Indeed, the modern cosmological model is called the **ΛCDM** model, where lambda (Λ) stands for the cosmological constant, and CDM is **cold dark matter**.

ΛCDM *cosmological model*

Cosmologists have gained substantial confidence in this cosmological model from such a precise fit between observations and theory. They can also extract very precise values for cosmological parameters which previously were only known with low accuracy. The CMB is such an important cosmological observable that every effort is being made to extract all of the information it contains. More space missions are being prepared to observe even finer details. They could provide experimental evidence for inflation, perhaps detecting **gravity waves** as predicted by inflation models (detectable by their effect on the CMB) and also provide information about elementary particle physics at energies far beyond the reach of man-made accelerators.

## 33–10 Finally . . .

When we look up into the night sky, we see stars; and with the best telescopes, we see galaxies and the exotic objects we discussed earlier, including rare supernovae. But even with our best instruments we do not see the processes going on inside stars or supernovae that we hypothesized (and believe). We are dependent on brilliant theorists who come up with viable theories and ideas and verifiable models. We depend on complicated computer models whose parameters are varied until the outputs compare favorably with our observables and analyses of WMAP and other experiments. And we now have a surprisingly precise idea about some aspects of our universe: it is flat, it is 13.7 billion years old, it contains only 4% "normal" baryonic matter (for atoms), and so on. These precise results might suggest that we live at a very interesting time.