or 10^{-12} second, it was so blistering that the massive W and Z particles existed in great profusion.

The Standard Model fully describes the behavior of matter and the evolution of the universe after this moment. But to understand what occurred *before* this instant, we have to call upon speculative theories like GUTs that take us beyond the Standard Model, where superhigh energies and ultrashort distances are the norm. There are several important questions whose answers must lie in these earliest moments of creation. Where did all the matter in the universe come from? How did it become structured the way it is? Why is it so smoothly distributed on the average?

Although the answers given by these speculative theories must be taken as conditional, the general outlines of this earliest trillionth of a second have begun to take shape over the past decade. The excess of matter (over antimatter) in the universe, for example, is thought to be closely tied, in part, to the phenomenon of CP violation discovered in 1964 (see Chapter 3). This slight asymmetry between processes involving matter and antimatter, when combined with conditions that should have occurred at about 10^{-34} second, could have produced such an excess—together with the vast quantities of photons that fill the universe. The ratio of photons to matter particles, in turn, helps physicists distinguish among various unified theories.

The overall smoothness of the universe is now thought to have arisen at about the same instant due to a unique phenomenon known as *inflation*. It was discovered in 1980 by Alan Guth, a particle theorist then working at SLAC, who was applying GUTs to the early universe. According to the inflation idea, the entire universe observable today compressed to a size smaller than a trillionth the diameter of a proton at 10^{-35} second, but it exploded violently to at least the size of a grapefruit (and perhaps a billion billion times bigger!) in the blink of an eye. The fabric of space was stretched so rapidly, like a balloon suddenly inflated, that it became extremely smooth.

Despite its overall smoothness, however, matter was somehow able to collect into the galaxies and clusters of galaxies now sprinkled about the universe. To accomplish such a feat, there had to be some kind of primeval lumpiness that survived this inflationary epoch—to supply the necessary "seeds" toward which matter could begin to gravitate.

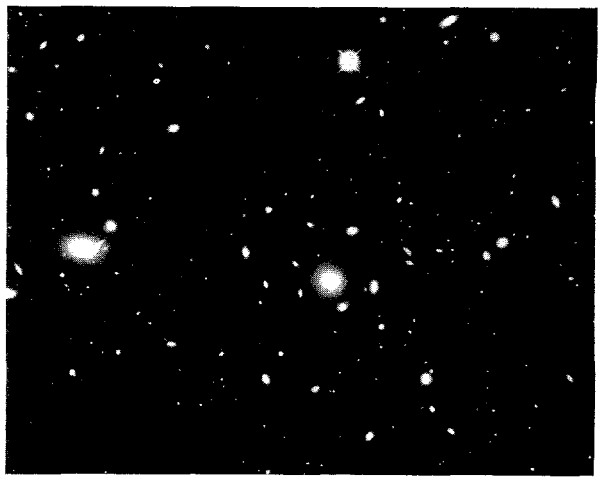

Figure 22. A cluster of galaxies in the constellation Coma Berenices.

Gauge theories propose two ways this lumpiness might have arisen. Quantum fluctuations during inflation could have produced tiny ripples in the otherwise smooth density of primordial matter. Or other phenomena resembling ruptures might have occurred in space itself—incredibly massive loops and filaments known as *cosmic strings*. In the billions of intervening years, matter would have swarmed toward seeds like these, producing the huge blobs and spirals we call galaxies.

While solving the smoothness and structure problems, however, inflation posed another riddle for cosmologists. It requires that there be far more matter around than has yet been spotted by astronomers—10 to 100 times as much. In the 1970's astronomers had begun to suspect that there was indeed more matter in the universe than what was visible. The luminous stuff seen with telescopes is about 10 times less than what is needed to explain the pinwheel motions of the spiral galaxies. Some form of as yet unseen *dark matter* has to exist in intergalactic space, causing this rapid rotation. But until inflation was proposed, this dark matter could have simply been baryons that had not been detected yet, normal matter that somehow does not shine.

Inflation requires there be so much matter around that, if true, the dark portion cannot be composed merely of baryons. Something else must contribute at least 90 percent of it. A possibility consistent with GUTs is that at least one type of neutrino has a non-zero mass. There are tremendous numbers of neutrinos—about a billion for every proton. If just one type has a mass only 0.01 percent of the electron's, neutrinos would *dominate* the total mass of the universe. Precise measure-