Chapter 32. Cosmology: Past, Present, and Future of the Universe

Note. We conclude our study of the astronomy by considering ideas of the very early universe and the possible long term fate of the universe.

Note. The study of the universe as it now appears is *cosmology* and the study of its origin is *cosmogony*.

Note. The assumptions of cosmology are:

I. The laws of physics can be applied to the universe as a hold (not just locally).

II. The universe looks the same at all points (i.e., it is *homogeneous*).

III. The universe looks the same in all directions (i.e., it is *isotropic*).

The last two assumptions together are sometimes called the *Cosmological Principle*.

Note. Einstein's general theory of relativity predicts that the universe must be expanding. This leads to 3 possible outcomes:

1. *Closed Universe.* The universe is positively curved, with no boundary but finite in extent. The expansion will eventually halt and a collapse will start.

2. *Open Universe.* The universe is negatively curved, with no boundary and infinite in extent. The expansion will continue forever.

3. *Flat Universe.* The is no curvature, expansion will be exactly balanced by gravity, but there is no collapse.

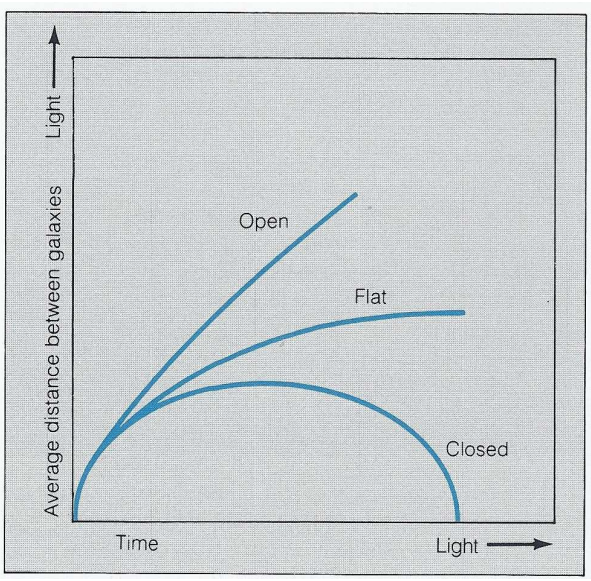

Figure 32.6 Page 622. Three Possible Fates of the Universe.

Note. A problem with the standard big bang is explaining the symmetry in the observed universe. The near balance between open and closed is also surprising. The *inflationary universe* model explains this as follows. When the universe cooled to 10^{27} °K, small regions ("bubbles") of space separated from the rest of the universe and expanded very rapidly. No communication between bubbles is possible and each bubble becomes a "universe."

Note. We now describe the early universe. In the first 10^{-35} seconds after the big bang, only the elementary particles *leptons* and *quarks* were present, controlled by gravity and a unification of the other 3 forces. After 0.01 seconds, the temperature

was 10^{11} °K and electrons and positrons appeared. After 1.01 seconds (when the temperature dropped to 10^{10} °K), protons and neutrons appeared. In the first 4 minutes, nuclear reactions took place, and 22%–28% of the mass was in the form of He. Sometime in the first billion years, galaxies and clusters of galaxies clumped out. The expansion and cooling continued until today (the temperature today is 2.7 °K).

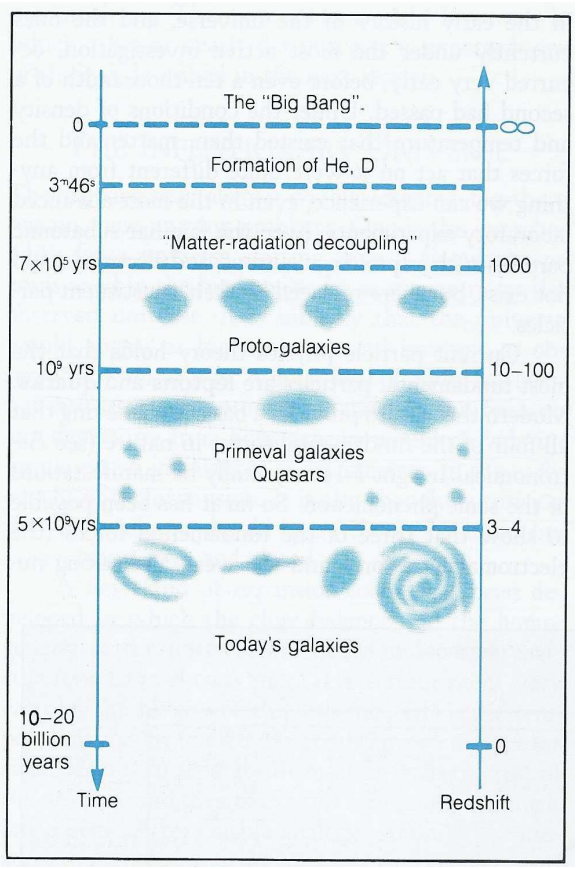

Figure 32.13 Page 630. The Evolution of the Universe.

Note. We now discuss possible ends for the universe. If the universe is open, it will continue to expand and cool. After 10^{14} years the hydrogen supply will be exhausted. All planets will be absorbed by dead or dying stars by 10^{17} years. Galaxies will dissipate by 10^{18} years. By 10^{32} years most protons will have decayed leaving free positrons, electrons, black holes, and radiation. By 10^{100} years the black holes will evaporate. If the universe is closed, the expansion will halt, maybe after 20 billion years, and a collapse will occur. The universe would then end in a "big crunch," possibly followed by a new big bang and a new universe.

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