Chapter 19. The Universe

Cosmology studies the origin, structure, and evolution of the Universe.

Olbers' Paradox

If the Universe is infinite and is uniformly filled with stars and galaxies that do not evolve, then the sky should be as bright as the surface of the Sun. However, the sky is dark. This is known as Olbers' paradox. What is wrong with Olbers' paradox is that the Universe expands, the Universe is not infinite, and stars do evolve.

Cosmological Principles and Cosmic Background Radiation

Copernican Principle - The Earth is not special.
Cosmological Principle - No place is special.
Perfect Cosmological Principle - No space or time is special.

The Cosmological Principle leads to George Gamow's Big Bang Theory. The Universe started with the Big Bang, and expanded. Initially, the Universe had such a high density and high temperature that fusion produced heavy elements. The initial radiation field has expanded and cooled to a lower temperature.

The Perfect Cosmological Principle leads to Bondi, Gold, and Hoyle's Steady State Theory. In this theory, the Universe expands and new matter is created at a rate of 4 atoms/yr/km^3. This rate is too small to be detected, as the density of air at sea level is much higher, 10^{37} atoms/km^3.

In 1965, Penzias and Wilson from the Bell Laboratories detected a minimum, uniform level of radiation at 10 cm wavelength in all directions of the sky. Further observations show that this background radiation has a spectrum of a 3 K blackbody. This *cosmic microwave background radiation* is predicted by the Big Bang Theory. Therefore, the Cosmological Principle and the Big Bang Theory become the accepted premises.

The Cosmic Background Explorer (COBE) satellite refined the background radiation temperature to 2.735 K. The cosmic background radiation is isotropic. The temperature is 0.003 K higher in the direction of Leo and 0.003 K cooler oppositely. This is caused by the combined motion of the Sun, Galaxy, Local Group, and local supercluster, at ~600 km/s toward Leo.

The Structure of the Universe

Gravity acts against the expansive motion of the Universe. Depending on the average density of matter (both luminous and dark) in the Universe, three fates are possible: 1) closed, 2) open, and 3) marginally open. The marginally open universe will come to a stop at infinity.

Based on Newtonian view of gravity, these three fates corresponding to cases in which expansion velocities are smaller than, larger than, and equal to the escape velocity, respectively. In general relativity, gravity is the result of curved spacetime, hence the three fates of the Universe correspond to positive, negative, and flat curvatures of the spacetime, respectively.

The age of the Universe depends on the model. The age of a marginally open universe is equal to 2/3 of the Hubble time ($1/H_0$), while that of an open universe is larger and closed universe smaller.

The models can be tested by observations. The redshift-magnitude plots cannot distinguish among the three models. The average density of the local universe can be measured; while the density of the luminous matter is too low to close the universe, the density of the luminous and dark matter combined may reach the critical density and make the Universe marginally open. The ages of the oldest globular clusters can be used to constrain the age of the Universe. The stellar ages agree with the age of the Universe within a factor of 2.

The Origin and Evolution of the Universe

Various theories have been developed to describe the origin and evolution of the early Universe. The temperature and density were so high that new theories are required. For example, Grand Unification Theories (GUTS) combining all four force are used to explain the Universe at a temperature of 10^{27} K. At a still high temperature (10^{33} K) and density, even the theory of general relativity no longer applied, and a Theory of Everything was invented to explain the Universe.

The Big Bang theory is challenged by four problems: horizon problem, flatness problem, matter-antimatter problem, and clumpiness problem.

The Theory of Inflation, which has dramatically modified the very early moment of the Big Bang, can explain the horizon and flatness problems of the early universe. A slight excess of protons over antiprotons in the beginning can explain the matter-antimatter problem. The energy fluctuation generates the lumpiness in the Universe.

The theories may not be correct, but at least there are predictions that can be tested by particle physics experiments or satellite observations of the Universe.