Chapter 15
The Cosmic Microwave Background

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ABSTRACT

The cosmic microwave background (CMB) holds many secrets of the origin and the evolution of our universe. This ancient radiation was created shortly after the Big Bang, when the expanding universe cooled and became transparent, sending an afterglow of light in all directions. It is a pattern frozen in place that dates back to 375,000 years after the birth of the universe. Numerous experiments and space missions have made increasingly higher resolution maps of the CMB radiation, with the aims to learn more about the conditions of our early universe and the origin of stars, galaxies, and the large-scale cosmic structures that populate our universe today.

Our universe began 13.8 billion years ago and has evolved from a single point of extreme heat and infinite density to the rich and complex universe of stars and galaxies that we see today. The early history of our universe was imprinted on the cosmic microwave background, or CMB in short, which is believed to be the relic radiation of our infant universe. Initially known as the primeval fireball, CMB consists of a wealth of information of the universe when it was only 375,000 years old, before any stars or galaxies ever existed. It is a crucial source of information to understand the evolution of our universe. Thus, by studying the properties of this radiation, we can learn about the conditions of our early universe and the origin of stars, galaxies and the large-scale cosmic structures that populate our universe today.

THE DISCOVERY OF THE CMB

The detection of electromagnetic radiation that fills all space, known as the cosmic microwave background (CMB), was again by chance, similar as the accidental detections of radio emissions from our Milky Way galaxy in 1931 by Karl Gurthe Jansky and from our Sun in 1942 by James Stanley Hey. In 1964, Arno Allan Penzias and Robert Woodrow Wilson were working on a 20-foot horn reflector antenna owned by

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Bell Telephone Laboratories at Crawford Hill, Holmdel, New Jersey. They refitted the antenna and built a Dicke radio receiver for radio astronomy use. After accounted for atmospheric absorption and ohmic losses, their measurements showed persistent noise that could not be accounted for regardless of which direction the antenna was pointing. This excess noise had a blackbody temperature of approximately 3.5 K at 4080 MHz, and Penzias and Wilson were trying very hard to get rid of that noise. They inspected every component of the equipment and initially thought that pigeons that frequented the antenna might be the cause. They even cleaned up pigeon's droppings in the antenna but the noise still remained.

In early 1965, a deeply frustrated Penzias happened to have a conversation with Bernard Burke from MIT. Penzias told him about the antenna excess noise that would not go away, and their fruitless efforts in figuring out the source of the noise. Burke told Penzias that he heard of the work by Robert Henry Dicke and his team members Phillip James Edwin Peebles, David Todd Wilkinson and Peter Roll at Princeton University about the search for a background signal from the early phase of the universe. Peebles is a theoretical physicist, and upon hearing Dicke's suggestion, he investigated and predicted the existence of the primeval radiation that permeates all of space. In order to test Peebles' prediction, Wilkinson and Roll, whom are both experts in radio technology, built an antenna on the roof of the Physics building in Princeton, trying to detect signatures of relic radiation from an early stage of the universe. After hearing of this research, Penzias made a phone call to Dicke and told him about the antenna excess noise. After hanging up, Dicke told his team: "Boys, we've been scooped".

The two teams then met at Crawford Hill. The Princeton team inspected the equipment (ironically, uses the radiometer techniques first devised by Dicke), went through the measurements and confirmed that the excess noise was indeed the background radiation from the early phase of the universe. These resulted in a pair of articles published in the Astrophysical Journal in May 1965. In one of the articles, Penzias and Wilson detailing the measurement of an excess antenna temperature of 3.5 ± 1.0 K that was unaccounted for and pointed to the other article preceded theirs by Dicke and his team for a possible explanation of the source. In the article titled "Cosmic black-body radiation", Dicke et al. discussed that the presence of thermal radiation remaining from the extremely hot early phase of the universe ("the fireball") was to be expected and the possibility of detecting it. They described their experiment at a wavelength of 3-cm although it had not yet produced any results, and also interpreted the findings by Penzias and Wilson at a wavelength of 7.3-cm as confirming the prediction of the "primeval fireball" theory. A radiation with a blackbody temperature of 3.5 K was interpreted as the remnant of the extremely hot early universe which then cooled as a result of the universe expansion, while preserving its thermal characteristic.

In 1978, Penzias and Wilson received the Nobel Prize in Physics for "their discovery of cosmic microwave background radiation".

THE EXPANSION OF THE UNIVERSE AND THE PREDICTION OF CMB

The fact that galaxies are moving away from us was first observed in 1917 when Vesto Melvin Slipher noticed that the light of the galaxies (or known as nebulae at that time) that he observed was red shifted, indicative of recession motion of the galaxies. The idea that the universe might be expanding was first demonstrated by Alexander Alexandrovich Friedmann in 1922 after working with Albert Einstein's theory of general relativity. However, Friedmann's work was not well received, and Einstein himself insisted on a static universe. Earlier in 1917, in his obstinacy to have an unchanging universe, Einstein

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