Our Universe is expanding — distant galaxies are moving further away from each other. Using the laws of general relativity and some knowledge of the Universe’s constituents, we can trace the evolution of the Universe backwards in time to an era when the density of matter and radiation was significantly higher and a plasma of photons, electrons and nuclei existed in thermal equilibrium. At a temperature of approximately 3,000 K (when the Universe was about 400,000 years old), atomic hydrogen formed and the Universe became transparent.

Although the CM B is remarkably uniform from place to place in the sky, small anisotropies in its temperature indicate perturbations in density that are thought to have grown into galaxies and large-scale structure in the contemporary Universe. By assuming that the perturbations originated at very early times, and have roughly equal amplitude at all length scales, we can obtain a good fit to observations of the anisotropies as a function of angular scale. Perturbations of different wavelengths evolve differently as the Universe expands, but they do so in a calculable way that depends on cosmological parameters such as the Hubble constant and the energy density, as well as on the amplitude of the initial fluctuation. Observations of these anisotropies therefore reveal a great deal about the characteristics of our Universe.

Perhaps the most significant aspect of the WMAP results is not the discovery of an unexpected feature of the Universe, but the confirmation of the generally accepted cosmological model that has been constructed over the past several years. In this model, the Universe is spatially flat and 14 billion years old, with an energy density consisting of 30% matter and 70% dark energy (a smoothly distributed component that varies slowly, if at all, as the Universe expands). The matter comes mostly in the form of dark matter, which is believed to be made of a type of particle that is as yet undetected; only 4% of the total energy density of the Universe is ordinary matter (such as stars, planets, gas and dust). Although this model is consistent with a wide variety of observations, it is clearly problematic from various points of view. As ordinary matter and dark matter presumably originate through very different mechanisms, why is their abundance so similar (within an order of magnitude)? Worse still, why is the total abundance of...
In 2001, the Cosmic Background Imager (CBI) telescope detected fluctuations in the microwave background that may be the first evidence of tiny temperature differences that led to the formation of the large-scale structure of the Universe.

But WMAP has done more than simply confirm other experiments. A crucial finding was the measurement of a polarization signal in the CMB, which was first detected by the DASI telescope last year. WMAP has provided images of CMB anisotropies that cover the entire sky and yet resolve features as small as 0.3 degrees. One obstacle to the construction of all-sky CMB maps is the need to distinguish the sought-after CMB signal from foreground emission from sources both inside and outside our Galaxy. WMAP (like other experiments) achieves this by producing maps in five different frequency bands, and using differences in frequency dependence to separate foreground emission from signal. Fits to the resulting spectrum of anisotropies provide constraints on cosmological parameters that are in excellent agreement with previous data.

But WMAP has done more than simply confirm other experiments. A crucial finding was the measurement of a polarization signal in the CMB, which was first detected by the DASI telescope last year. WMAP has detected polarization at large angular scales, correlated with the temperature fluctuations themselves. This effect, which developed long after the CMB formed, is due to the reionization of the Universe by high-energy radiation from the first generation of stars. The WMAP findings indicate that these first stars formed when the Universe was only 200 million years old, earlier than previously believed.

A pessimist might worry that the field will become a victim of its own success. The provisional cosmological model fits the observations very well, and one could imagine a future of increasingly precise measurements of cosmological parameters without significant improvements in our fundamental understanding. It seems more likely, however, that a future generation of new experimental approaches (searches for gravitational waves, direct detection of dark matter) will yield their own surprises. Many of the deepest cosmological mysteries remain — the origin of the matter-antimatter asymmetry, the nature of dark matter and dark energy, and the smoothness of initial conditions in the Universe (perhaps a result of inflation). It’s a good bet that the fun is only beginning.

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